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MOLDING SANDS OF MICHIGAN
AND
THEIR USES

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To the Director, and the Board of Commissioners of the Department of Conservation of the State of Michigan:

P. J. Hoffmaster, Director
Wm. H. Loutit, Chairman
Philip Schumacher
Harry H. Whiteley
M. J. Fox
Philip K. Fletcher
Joseph P. Rahilly
Wm. J. Pearson
Wayland Osgood, Secretary

Gentlemen: I have the honor to submit herewith a report entitled "The Foundry Sands of Michigan", and recommend that it be published and bound as Publication 41, Geological Series 35, of the Geological Survey Division, Department of Conservation.

This report represents several years of field work and laboratory study and testing by Dr. George G. Brown of the University of Michigan, and a great many analyses and tests at the University of Cornell, New York, and the Bureau of Standards, Washington, D. C., under the direction of Dr. H. Ries, head of the Department of

Geology, Cornell University, with the financial assistance of the American Foundrymen's Association. The report adequately answers the demand of the foundry sand industry for a comprehensive discussion of the molding sands of the State, and may well stimulate a revival of the molding sand industry in Michigan.

The report contains a discussion of the sands of the State, and the results of an exhaustive study of the bond in foundry sands. The investigation of sand localities proved that although the deposits are very large, very few are deposits of naturally bonded sand. The cost of importing bond sand from such localities as the Albany Molding Sand district of New York, and the resultant lagging of the foundry sand industry in Michigan far behind the progress of the iron and steel industries, led to a laboratory search for a synthetic molding sand. Laboratory experiments conducted in the University of Michigan Laboratory, under the direction of Dr. Brown, by Dr. C. C. DeWitt, now professor of chemistry at the Michigan College of Mines, were highly successful in producing a synthetic bonded sand from unbonded sands in the State, and a simple and cheap method for the manufacture of the artificial sand was developed. This discovery may prove revolutionary and develop the large resources of sand in Michigan.

The report thus fulfills the requests of an important industry and opens the way for future development of a once despised resource.

Very truly yours,
R. A. SMITH,
State Geologist.

PREFACE

This investigation was started largely at the suggestion of the American Foundrymen's Association, and foundrymen of Michigan, to locate, if possible, any usable molding sand in the State of Michigan. Although there seemed little chance of finding any appreciable deposits of such material, definite results of either positive or negative nature were considered important as a complement to the report of Foundry Sands by Ries and Rosen published in 1908 as part of the Michigan Geological Survey Report for 1907.

As indicated, this report deals mainly with molding sand, but because many Michigan sands are more readily adapted to other uses, at least brief descriptions of the properties necessary and desirable in sand used for other purposes have been included. It is thought that the inclusion of this information may prove of use to those residents of Michigan who wish to estimate the possible economic value and uses of various sand deposits occurring within the State, as well as aiding those foundrymen and other commercial users of sand who wish to find new deposits, within the State, of materials adaptable for their purpose.

The field work was started in the summer of 1923 in conjunction with other field work. Practically no field work was done the following year due to the press of work completing the report* on Clays and Shales of Michigan. During the summer of 1925 the field work was completed with the assistance of Dr. C. C. Furnas, now professor of chemical engineering at Yale University.

As there are few deposits of naturally bonded sands within the State, investigation was conducted in the laboratory to determine, as far as possible, the fundamental factors responsible for the bond in natural bonded sands with the idea of indicating how such sands might be prepared synthetically from the unbonded sands so common in Michigan. This investigation was successfully conducted by C. C. DeWitt, now professor of chemistry at the Michigan College of Mines and Technology, Houghton, Michigan, during the years 1925 and 1926.

The first part of this bulletin includes a discussion of the physical and chemical properties of sand and the results of this investigation of the cause of bond in naturally bonded sands.

The second part is a detailed description of the sand areas and deposits throughout the State with a complete table giving all of the properties of the sands which have been tested. This description is arranged alphabetically according to counties for the Southern and Northern Peninsulas respectively. By comparing the specifications required of sand to be used for different purposes as given in the first part of the report with the tabulated physical properties of the sand in the second part, an approximate idea of the possible economic uses of the various sands may be readily obtained.

With the increasing recognition of the advantages of synthetic or artificial bonded sands for use in foundry practice, it seems reasonable to expect that some of the unbonded sands of the State may, in the not far distant future, be used in preparing bonded sand for molding purposes. This conclusion seems the more probable because of the high freight charges paid in importing sand from other districts, frequently as far as the Albany Molding Sand Districts in New York. It seems reasonable to expect that high quality artificial molding sands may be prepared at a cost (exclusive of digging or recovering the sand) less than the freight differentials between points in Michigan and the present shipping points of molding sand from without the State.

With a few exceptions of suspicious ignorant folk, everyone throughout the State cooperated fully in supplying information that is essential to a report of this kind. A number of the samples collected, during the summer of 1923 were tested under the auspices of the American Foundrymen's Association at Cornell University and at the Bureau of Standards. In some cases duplicate samples were also tested in the University of Michigan in Ann Arbor, for purposes of comparison.

The cooperation of many persons throughout the State and of the American Foundrymen's Association in testing about one hundred and fifty samples is gratefully

acknowledged. In addition to those mentioned, Dr. A. E. Carr, now Dean of Engineering in Wayne University, helped with the field work during the summer of 1923; Dr. G. G. Lamb, now assistant professor of chemical engineering, New York University, made the routine physical tests of the Michigan sands not done through the cooperation of the American Foundrymen's Association, and prepared the tabulation of the physical properties. The work was originally conceived, promoted, and finally carefully reviewed by Dr. R. A. Smith, State Geologist. Without his patient effort this bulletin would never have been prepared.

GEO. GRANGER BROWN.

June 25, 1928, Nov. 28, 1934.
Ann Arbor, Mich.

*Pub. 36, Geol. Ser. 30, Mich. Geol. Surv. Div. Dept. Conservation, 1926.

Chapter I. ORIGIN OF SAND

DEFINITION

GENERAL

Sand is the general name applied to comparatively finely divided, unconsolidated grains of rock, minerals, or slag. For this report only the naturally formed product will be considered. Although this report is concerned primarily with foundry sand, it is perhaps well to consider briefly other important uses of sand. Concrete, plaster and similar sands used in construction represent by far the largest consumption of sand. Foundry sands rank next to construction sand in volume of output. For steel work a high silica content is essential for proper refractory qualities. Some molding sands for the non-ferrous metals contain not more than sixty or seventy percent of silica. Sands used for other purposes such as: the manufacture of glass, engine sand to prevent slipping of locomotive wheels, abrasive in grinding operations, filter sand at municipal water filtration plants, fire or furnace sand for lining the bottom of furnaces, as well as sand for other special uses will be discussed briefly as references to them occur in the text.

Foundry Sands

A definition of foundry sands will include many sands which cannot be regarded as ideal, but which are profitably and satisfactorily used by the foundries.

Molding Sand. Any material which when moist can be formed into a mold from which usable metal castings may be made is known as molding sand.[1] This definition includes the natural-bonded molding sands which are mixtures of sand, clay and colloidal matter occurring in Nature, and similar artificial mixtures generally referred to as synthetic molding sands.

Core sands used in preparing cores are lacking in bond or strength and are always bonded by the mixture of some additional agent, which supplies the strength to the sand so that the prepared mixtures can be molded into the large core which then possesses the required strength to secure a satisfactory core for the casting. *Core sands* may then be defined as sand which can be artificially bonded and used in the preparation of satisfactory cores.

[1]M. S. Littlefield, Bulletin No. 50, State Geological Survey, Illinois, page 20.

ORIGIN

The difference between core and molding sands is essentially the absence of bonding material in the core sands, and the presence of clay and colloidal matter in the bonded or molding sands which gives them the desired property of having strength or cohesiveness so that no artificial bonding agent is necessary in preparing molds for metal castings.

In addition to these forms of unconsolidated sand deposits, there is a large group of consolidated deposits, classed as sandstone and quartz or silica rock, which are crushed and provide a very satisfactory clean sand for use in preparing cores and other artificial sand mixtures for foundry use.

All of the unconsolidated sands of Michigan are, geologically speaking, young, being of the glacial or Pleistocene Age.

The natural processes by which the sand was formed from the bedrock and then transported and deposited during the glacial period were perhaps somewhat different in degree from the similar processes occurring today but undoubtedly identical in principle. These processes should be considered under four heads:

1. Disruption or disintegration
2. Transportation
3. Deposition
4. Secondary changes

DISRUPTION OR DISINTEGRATION

The primary source of all sands is pre-existing rock. The disruption or disintegration of this rock may have been accomplished by chemical means such as solution in rain water, or mechanically by the breaking of the rock into fragments either by changes in temperature causing alternate expansions and contractions of the rock itself and by the freezing of water in the pores and cracks of the rock, or by the growth of vegetation in and through the cracks ultimately breaking the larger rocks into small pieces; by wind through abrasion of sand grains on exposed rock surfaces or through the uprooting of trees growing on rocks; or by glaciers moving over the surface.

Glacial Decomposition and Solution are active on the more soluble rock minerals, reducing the original rock to an insoluble residue termed clay, the dissolved mineral salts being carried away by water. This form of

decomposition produced sand particles only when the minerals of the original rock contained at least one widely different and relatively insoluble mineral substance.

The relatively large amount of soluble material contained in any sand deposit indicates that chemical decomposition has been much less important than mechanical disruption. Chemical decomposition continues in such sands after deposition and in some deposits decomposition locally has been an important factor in the production of natural-bonded sands. Coming down from the north bearing a tremendous load of rock debris scored from the surface of Canada, the ice completely covered the State of Michigan and most of the area north of the Ohio and Mississippi rivers. When the ice sheet retreated this debris composed of boulders, sand, and clay was deposited on the surface of Michigan either as a direct deposit from the glacier or as a material transported from the ice sheet in streams of water issuing therefrom, or deposited by water in glacial lakes. These water deposits are classed as glacial out wash, fluvial and lacustrine deposits.

TRANSPORTATION

Glacial. If the material furnished by the ice sheet had simply been deposited as glacial debris on the surface of the earth without any further transportation or classification, it would not be satisfactory material for any foundry use without expensive artificial separation and classification. Glaciers transport all sizes of material without sorting.

Streams, on the other hand, move gravel, silt, clay, and dissolved salts, but with a given velocity they can pick up and carry sediment only up to a certain size, all larger fragments being left behind. An ordinary sluggish creek may pick up and carry gravel and sand during a flood, but as the flood stages retire only the fine sand and silt can be carried, while at the still lower stages of the creek only clay can be transported. Finally at low water the stream will be clear, its velocity being too low for it to carry sufficient clay to make the water roily. The sorting action of streams in transporting material is very delicate and in direct contrast to that of glacial transportation.

The wind generally picks up and transports only sand, silt, and clay when such material is loose, dry, and unprotected by vegetation. Its tendency to sort this sediment into different grades of sizes is pronounced, but less so than that of streams.

Transportation in streams and by the wind is now taking place in Michigan in much the same manner as occurred immediately after the glacial period. The shifting sand dunes along the east shores of Lake Michigan are a clear example of present transportation by wind. Every stream and river in the state is continually transporting boulders, sand, silt, and clay, and depositing this material in the same manner as has been done for ages.

DEPOSITION

Glacial deposition is due largely to the melting of the ice and the consequent releasing of the inclosed rock material. The term glacial drift is applied to all such deposits. If for a time the melting of the ice front progresses at the same rate as the forward ice movement of the ice across the country, much of the material carried along in the ice is deposited in a relatively narrow belt along the ice front. The glacial debris is deposited very unevenly, resulting in a hilly, hummocky, or knobby surface, with many deep depressions called "kettles." Such belts or areas of glacial deposits are called *moraines*. They are composed chiefly of a heterogeneous and variable mixture of boulders, pebbles, sand, and finely ground rock particles. The term *boulder clay* or *till* is applied to the unsorted mixture of glacial material. Locally the material is water-sorted, resulting in "pockets" of sand and gravel in the moraines.

If the melting back of the ice margin is faster than the forward movement of the ice the deposits are spread out in the form of gently undulating plains. These deposits are largely of debris carried along beneath the ice or in its lower portion. The term ground moraine or better till plain is applied to such deposits. Some of the material is sorted in the channels of streams beneath the ice and left in the form of ridges of sand and gravel, called eskers or hogbacks. Except for the hogbacks deposited along subglacial stream channels, very little sand or gravel occurs within till plain deposits, but in many places these sheets of till are thin and lie on deposits of sand and gravel belonging to an earlier sheet of glacial material.

Both the morainic and till deposits are of widespread occurrence in Michigan. They are conspicuous for the predominance of unsorted material.

Deposits of usable foundry sand in the moraines are generally confined to the flanks of knobs. The thickness of the sand is usually greater at the base and thins upward, grading into sharp sand and gravel at the top. The deposits are generally very small and vary rapidly in grain size. In eskers, the deposits of sand and gravel show rapid variation within very short distances vertically and horizontally, indicating rapid changes in velocity of the sub-glacial stream. Morainic or till deposits are unfavorable sources of satisfactory foundry material and demand the best experience and pit management to produce even a fairly uniform grade of sand.

River or Stream Deposits

Fluvial deposition tends to sort the sediment into size grades, and for this reason offers greater promise in the production of commercial material. If a rapid stream carrying sediment generally decreases in velocity down stream the gravel and then coarse sand are dropped first, followed progressively by finer material, until in almost still water silt and mud or clay are deposited. But the completeness of the sorting or separation of the different sizes of materials at any one point depends

upon the rate of decrease of velocity. It is clear that uniform fineness in a deposit must be dependent upon constant conditions of deposition over a considerable time, as were maintained for considerable periods in those streams which flowed rapidly from the terminals of the glaciers and carried with them some of the material deposited by the ice sheet, as it melted.

Simultaneous deposition of sand and clay without fine sand and silt is an impossibility. There is a remote possibility that alternate layers of sand and of clay might be deposited in such a proportion that the resulting section could yield a satisfactory molding sand composed of sand and clay without large amounts of fine sand and silt. For this reason, the actual formation of a bonded sand containing sand particles and clay without large quantities of fine sand and silt is usually dependent upon secondary changes occurring in the sand after deposition.

Deposits in Glacial Outwash: During the period that the Great Ice-sheet retreated northward across Michigan extensive plains of gravel and sandy material were deposited by the many streams which issued from the melting ice front. Some of these deposits are spread out like large aprons or fans. Others form relatively narrow belts marking the channels of former streams, as in the case of deltas. This type of deposit is characterized by the flat nature of its topography. The outwash trends roughly southward from the terminal moraines.

In many places the deposits of outwash streams were fairly well sorted and the sharp sand is of a fairly uniform size. However, the possibility of depositing clay with this sand to form naturally bonded sand is so small that we seldom find any naturally bonded sand in glacial outwash aprons.

If any bonded sand is in these deposits it is very probable that it has been developed by secondary changes after the deposition of the sand. *Weathering*, the process of producing secondary changes, seems to take place best on the large flat areas and is aided to some extent by the covering of vegetation which furnishes organic acids which help in the solution and decomposition of the sand particles forming clay and colloidal matter which supplies the bond in the sand.[2] [3] The sand of the Albany district is composed entirely of quartz or chert grains which are very insoluble under ordinary weathering conditions. The grains are coated with a strong type of clay which does not extend below the zone of weathering or the level of ground water where sharp sand or gravel is encountered. Clay bond in these deposits has been formed by the weathering of the soluble minerals out of the sand particles. Other examples of this type of deposit are found in extensive outwash flats south of Burlington, Wisconsin, and in similar outwash plains in southwestern Michigan.

[2]D. H. Newland Albany Molding Sands, New York, New York State Museum Bulletin 187, 1916,

[3]C. M. Dennen Albany Molding Sands of the Hudson Valley, New York State Museum Bulletin 273, pp. 19-20, 1925.

Deposits Along Abandoned Drainage Lines. Occasionally the streams flowing from the ice deposited much sand and gravel in the valleys through which they were flowing. Such streams often clogged the valley with sediment to such an extent that the stream was frequently forced to find another course. Abandoned drainage lines leave filled valleys with no permanent or persistent streams flowing through them.

In numerous places the deposits of old glacial streams are sufficiently well sorted to yield satisfactory foundry material. In such deposits the sands are usually found under flat top terraces where a relatively thin deposit may be sufficiently well bonded to serve as satisfactory molding sand.

Deposits Along Present Lines of Drainage. In areas of deposits by the old glacial streams, a smaller stream frequently persists after the retreat of the glacier. These later, present streams cut through the old deposits leaving the sand as terraces above the bed of the stream.[4]

The last deposition on the top of these terraces is frequently bonded molding sands, as in the Zanesville, Ohio, district, where the currents and the material supplied by the streams were favorable for depositing essentially the proper mixture of sand and clay to form a molding sand. Below the molding sand cover there is usually a much greater thickness of sharp sand and gravel. The "Red Flint" blast sand produced at Eau Claire, Wisconsin, comes from such a terrace which was made by the Chippewa River cutting through the sand previously deposited by the old glacial river.

[4]J. A. Bownocker, Muskingum County, Sand and Gravel. Geological Survey of Ohio, Fourth Series, Bulletin 21, p. 341, 1916.

Lacustrine or Lake Deposits

Glacial Lakes. Locally the old glacial streams or rivers flowing from the terminal of the glacier were dammed by a large deposit of material dropped by the streams or by the edge of the glacier forming a temporary dam across the valley in which the stream was flowing. The sediment, varying from the coarse sand to fine clay, carried by the streams running into these lakes spread over the lake bottom. The coarser material was deposited near the shore where wave action worked it over into sandy beaches or beach deposits and the finer material was carried further out into deeper and more quiet water. Many such deposits are found in Michigan along the old beaches and lake bottoms of the glacial lakes.

David W. Traynor, Jr.,[5] reports an analysis of the clay contents of the in the old lake bed at varying distances from the old beach ridge formed by the glacial lake Jean Nicolet in the Berlin District of Wisconsin. On the beach the sand had a clay content of 0.74 percent, two-tenths of a mile from the beach ridge the sand showed a clay content of 4 56 percent; the molding sand in the second foot below the surface and about one hundred feet further away from the beach ridge than the last sample

showed a clay content of 30.66 percent; and a sample taken a quarter of a mile from the beach ridge showed 47.42 percent of clay.

In these lake deposits it is reasonable to expect that the natural bonding material was deposited simultaneously with the sand grains using the term "simultaneous disposition" in a geological sense.

Because lake deposits may have been formed in this way and contain sand of the proper size grade deposited with clay bond as molding sands, in which the development of the bond is not necessarily dependent upon weathering, we may expect to find molding sand or naturally bonded sand in lake deposits independent of the penetration of weathering, or other secondary changes in the deposit.

[5]Geology of Molding Sand Deposits. The Transactions of the American Foundrymen's Association. Vol. 33, p, 707.

The Deposits Along the Shores of Present Lakes. The processes described above are actually occurring at the present time in many of the large lakes of this country which have marked shore currents.

Lake Michigan is a notable example of this sorting action of shore currents. The bluffs along the lake shore vary in height from a few feet to over a hundred feet near St. Joseph and are composed of glacial material consisting principally of sand and clay. The waves working on the bluffs sort this material, carry the clay out into the deeper portions of the lake and deposit the sand along the shore. The south-moving current along the west or Wisconsin shore of Lake Michigan caused by the northeast winds in this section cut into the shore line carrying the sand southward. This is evidenced in the large deposits of sand found piled up on the north side of any artificial or natural obstruction on the west side of the lake.

Eolian Deposits

After sediment has been picked up by the wind its place of deposition will depend in a large part upon the size of the sediment and upon its weight. The light particles will be blown higher and carried further than the heavier particles. With certain wind velocity the coarse sand may move by short leaps, the finer sand by longer leaps, and the clay remains in suspension in the air for long distances.

That size which moves very slowly is concentrated into dunes, the finer material is winnowed up and carried away. Sand dunes, therefore, occur very close to the source of the sand or sediment picked up by the wind. Because of the high effectiveness of the wind in sorting sediment according to sizes the sand contained in a dune is well sorted and generally of a uniform fineness. The finer windblown sediment which is removed from the sand deposited in the dunes is carried further and deposited later on the bluff or the rim of the valley wall.

This fine material of silt and clay and very fine sand distributed by winds over the country, is known as *loess* and is found in the Central Mississippi Valley especially in the states of Iowa, Kansas and Nebraska covering thousands of square miles. The thickness of the loess is not great varying usually from ten to twenty feet. It is generally supposed that this very fine material which in some cases carries small fossil shells has been blown into its present place from the surrounding flat country and was originally rock flour ground up very finely by the glacier and spread over the country. It is quite variable, sometimes showing more clay matter in places and even a great amount of lime in others. Loess deposits have been used for stove plate casting at several places especially at the stove foundries in Quincy, Illinois.

Loess deposits are almost lacking in Michigan. The soil, however, throughout the state carries a small amount of wind-deposited material which has rendered extensive districts in the southern part of the lower peninsula somewhat loamy that would otherwise be sandy.

The dune sands along the southern and eastern shores of Michigan are particularly important as a source of core sand. This sand has been well sized by the wind which in places near the mouths of the principal rivers has heaped the sand to heights of one hundred and fifty to two hundred feet above the level of the lake. The high dunes, however, are confined to within one or two miles of the shore of Lake Michigan.

Consolidated Deposits

Sylvania sandstone at the top of the upper Silurian series and varying from about thirty to three hundred feet in thickness, is present in the southeastern part of the state. Locally the Sylvania sand is practically pure silica rock and is mined by two companies near Rockwood and Steiner. When crushed and cleaned this material makes excellent core sand and base for steel sand in making steel castings, as well as being adapted for high grade uses as a glass sand.

SECONDARY CHANGES IN SAND DEPOSITS

It has been shown that it is improbable, except in rare cases, for sand and clay to be deposited simultaneously in the same place without the inclusion of very fine sand or silt. As many natural bonded molding sands are a mixture of sand and clay without fine sand and silt, obviously processes additional to those already considered must have operated on such deposits.

Most of the sand deposits were produced by mechanical disruption or by glacial action. Chemical decomposition and disruption of the sand particles may proceed after this sand has been deposited, as the soluble matter in the rock and mineral particles has not been removed by weathering or chemical action.

Continual leaching of the sand deposits by rain water and by ground water, particularly when they contain some absorbed carbon dioxide from the atmosphere, removes the soluble part of the sand grains, causing a disruption of the grain. The insoluble residue formed by chemical action is left in the interstices between the

grains as a deposit of clay. The insoluble particles of sand and mineral matter are left behind as sand grains.

Solution of soluble matter under these conditions in a practically neutral solution favor the formation of colloidal solutions and colloidal particles which are readily absorbed on the surfaces of the sand grain and on the surface of the clay. In this way a deposit of well sorted sand originally without bond, under favorable conditions of weathering may become a well bonded usable molding sand.

Molding sand formed in this way is generally the most valuable sand, as the action of the ground water removes practically all of the lime from the limestone, the alkali from the feldspar, and to a large extent the excess of iron that may be present, leaving the sand behind as essentially silica sand particles and a residue of clay, or aluminum silicate, between the grains.

Chemical disruption of the sand grains is very appreciably aided by organic acids contained in the water. For this reason a growth of vegetation over a sand deposit is an important factor not only in holding in place the deposit and preventing further transportation and sorting of the sand according to size, but also in supplying the chemical means for the continued disruption and solution of the sand grains. This weathering action tends to increase the refractoriness of the sand by the removal of lime, alkali, and some of the iron.

J. E. Fletcher[6] calls attention to the fact that the English molding sands are more ferruginous than those found in America. He credits this high iron content as being the cause of the greater durability of the English sand. In England the highly ferruginous sands are found on the outskirts of the coal measures where red sandstone comes into contact with the coal measures. Wherever there is any trail of volcanic action in these deposits, molding sand is found. When many of the American molding sands are burned or heated, they resemble in condition the naturally bonded English sand. Most of the Michigan sands that possess natural bond take on a dark red or brown color when heated to temperatures of 1000 to 1200 degrees F. The importance of colloidal ferric hydrate in a bond and the durability of the molding sands will be discussed later.

The action of weathering begins at the top of a deposit and causes a formation of clay in the upper layers. This heavy layer, as it is called by a producer of molding sands, may be a single thick horizontally continuous layer or it may be a series of thin horizontal layers from an inch or less to over a foot thick separated by somewhat thinner layers of sharp, clean sand. Upon casual inspection it might be supposed that these more or less horizontal layers of high clay content were due to stratification in the deposition of the sand. But this is not the case. In many deposits, such as wind blown or dune sands which are uniformly sorted from top to bottom, the clayey bands are found bearing no relation to the depositional stratification. In other deposits several stratified layers of different fineness may be included in a single clayey band. In general these deposits exhibit four distinct layers as follows:

(1) At the top a loam or reduced clay supporting vegetation.

(2) Below this a layer of medium fine sand containing some clay running into

(3) Sands of high clay content which are separated by a sharp sand usually coarser than found above the clay band, and

(4) below the clay band the sharp core sand continues as a uniform deposit practically free from bond.

Although these distinct layers are not always in evidence, owing to the fact that the Michigan deposits are still so young as not to have shown clearly the result of the weathering, in general, these four different layers are present or in the process of formation. In the deposits of uniform fineness the clayey bands run parallel to the top of the sand deposits and in their initial stages begin within a foot of the surface.

In Illinois where the sand deposits are considerably older than in Michigan weathering has continued in many places until the sands have merged into a thick heavy layer from five to fifteen feet thick.[7] The core sand deposits near Juniata, Tuscola County, contain only one or two clay bands. In these deposits which are the remains of old glacial lake beaches still relatively young compared to those found in southern Illinois, the weathering has not proceeded sufficiently to develop an appreciably high clay content. Apparently these deposits represent core sand, at present, or molding sand in the making.

Generally clay bands are more pronounced in the higher deposits above the level of ground water, and seem to be found only in those deposits covered by a surface of soil or some form of vegetation.

Exactly what causes the formation of these clay bands is not clear, but it seems reasonable in view of the facts mentioned that the clay deposited in these sands is obtained originally from the upper part of the deposit either by weathering action or directly from the soil on top of the deposit. A reasonable theory is that the protective action of the vegetable emulsoids on the colloids in the leaching water tends to hold the clay formed in the upper part of the deposit or picked up in the soil in suspension in a flocculated state. Water then descending through the deposit carries this clay with it until the unstable vegetable emulsoids are decomposed or oxidized on reaching the lower sand. This decomposition of the vegetable protective colloid causes deflocculation of the colloidal matter and the deposition of clay.

Within the clayey band all of the coarse grains are usually coated with limonite which suggests that the formation of ferric hydroxide or limonite in the sand

deposits may have some influence on the deposition of the clay in the band.

[6]Transactions of American Foundrymen's Association, Vol. 33, page 793.

[7]M. S. Littlefield in Bulletin 50, State Geological Survey of Illinois, Natural Bonded Molding-Sand Resources of Illinois, page 60.

SUMMARY

Uniform deposits of well sized material are to be expected only in the sand dune areas and in the deposits known as glacial outwash. Natural bonded sands may be found in small deposits along river terraces generally close to the river banks or in slope mantels formed by wind, or in strictly glacial deposits as at the lower part of the shoulder of drumlins, or in terminal moraines, but in general such deposits are small, variable and unsatisfactory. The best and most valuable natural molding sand is usually found in weathered dune areas or in glacial outwash aprons or in weathered deposits of uniformly sized materials produced by other means.

In Michigan, the sands are still young and generally have not been sufficiently well weathered to produce a satisfactory, durable sand for molding purposes.

Chapter II. PROSPECTING AND EXCAVATING SAND

To anyone superficially familiar with the surface geology of Michigan, prospecting for sand would seem an easy task, as sand or sandy soils seem to be almost everywhere in Michigan. Through the central part of the Southern Peninsula large areas which are composed of outwash plains left by the ice sheet offer vast deposits of well classified unbonded sand. The relative abundance of unbonded sands and lack of well classified bonded sands is reason for making a major attempt to locate possible sources of natural bonded or molding sand.

The better deposits of molding sand are most likely to be found in well weathered glacial outwash plains or in similar deposits of well classified or sized sand which have been exposed to the action of surface water for a relatively long time. A careful search through most of the glacial outwash plains of Michigan indicates, however, that these deposits have not been weathered sufficiently to form well bonded sand. In fact, the only areas which show any appreciable natural bond in Michigan are those areas indicated as moraines. These areas may have been subjected to some weathering, or washing by waters of lakes, ponds or streams, which helped to carry some of the clay bond from its original position to other nearby areas which may have contained fairly well classified sand.

It seems, therefore, that the only probable localities containing usable amounts of molding sand are the old lake beds in which the sorted material may have been mixed later with a clay bond, or in small areas of moraines. In such deposits it is not to be expected that any appreciable thickness of molding sand of uniform quality will be found. Somewhat similar deposits may have been formed in small inland lakes from moraines, the material being mixed and sorted by the streams running into these small lakes. There is also a possibility that small pockets of molding sand may be found in the moraines. These pockets will usually be found on the flanks of the knobs or drumlins, usually showing a greater thickness at the base and grading upwards into sand and gravel. Unfortunately the weathering process of the dune sand deposits of glacial outwash plains has not progressed to that degree necessary to form reasonably thick deposits of molding sand. In many of these beach deposits some clay bands have been observed indicating that the weathering process is under way.

Because of these conditions we may expect to find the best deposits of core sand or unbonded well sized sand in the sandy outwash plains, the lake deposits or beaches of old glacial lakes, and most important, in dune sands particularly along the eastern shore of Lake Michigan.

EXPLORATION OF DEPOSITS

When a deposit of sand has been located, the thickness, extent and character may be determined by thorough field examination. Because deposits of sand vary rapidly both horizontally and vertically it is important that careful test pitting or boring be clone at short distance intervals over the entire deposit. Auger borings are the most convenient to determine carefully the thickness and character of overburden, the thickness and general character of the bonded sand if present, and any changes in color or character of the sand as the borings are extended to greater depth.

Samples representative of different strata found in the deposits should be collected and a careful record taken of the thickness of each stratum represented by the sample. It is far better to keep the samples of the different layers separate and to combine them proportionately in the laboratories to represent an average sample, than to try to collect an average sample in the field, as frequently the real value of the deposit cannot be determined unless the different layers are kept separate.

A satisfactory auger for drilling sand deposits may be readily and cheaply made by welding a two inch carpenter's auger to a short length of three quarter inch pipe. By using a number of three or four feet sections of pipe which may be screwed in as the depth of the hole increases and a "T" to make a handle, the auger may be run down to a depth of thirty feet or more without trouble if the sand dones not cave into the hole. If the sand possesses sufficient bond, this caving does not occur. But if the hole tends to fill up, it is possible to keep the sand out of the hole by driving down a larger pipe and working the auger through the large pipe. Where a large

sample is desired, particularly, at limited depths, a post-hole auger or digger may prove more satisfactory than the small auger described.

MAPPING

The data obtained by means of boring is best coordinated by means of a large scale map of the deposit, the distance between borings being posted, and each line of boring paralleling the preceding lines of boring. The borings identified by numbers can then be compared with notes made in the field, for a preparation of a profile of the deposits through the different lines of holes.

A comparison of this profile with a large scale map, and the result of the tests on the various samples collected, will give an approximate idea as to the amount of sand of the desired quality contained in the deposit. Because the small quantity of sand taken in this way may not be representative of the different layers of the deposit, pits should then be sunk: through the supposedly workable sections of the deposits, and at least fifty pound samples obtained by mixing and quartering several hundred pounds of sand taken from this section of the deposit. Care must be taken in sampling to include no surface clay or soil but only that sand from the workable section. A number of samples taken in this way and tested by standard methods should give a satisfactorily accurate idea of the quantity of sand of the desired grade that may be recovered.

ECONOMIC FACTORS

DRAINAGE

Drainage of the deposits may in rare cases offer a serious problem, but generally sand deposits, at least in Michigan, are underlain by sand, so that the drainage occurs naturally without artificial means.

THE OVERBURDEN

The overburden, or the soil covering the sand has to be thoroughly removed before the sand can be recovered, in its clean state. For this reason, consideration of the extent and nature of the overburden are important in estimating the value of the sand deposits. The inclusion of unusable sand in an otherwise satisfactory deposit must also receive careful consideration as such inclusions must be avoided in digging.

MARKETS AND TRANSPORTATION

Core sand is a very cheap commodity usually selling for less than one dollar and at times as low as fifteen cents, per ton, f.o.b. For this reason, it is important that transportation facilities be readily accessible to the deposits and that the deposits be located at least reasonably near the large markets, so that the possible profit in working the deposits is not entirely consumed in transportation costs.

Molding sand, being a rather scarce commodity in Michigan, is frequently imported from New York or Ohio, with high transportation charges, so that in the case of a natural bonded sand it is not quite so important that the deposit be located close to the large markets.

RECOVERING OR PRODUCING SAND

As practically all structural sands as well as foundry sands, are recovered from unconsolidated deposits, the term mining or quarrying hardly applies in the usual sense. Perhaps digging or excavation is a better term for describing the methods used to recover or produce sands. Methods of working or excavating depend on the character and locality I the sand bed or sand bank, the output or capacity, and whether or not the sand requires subsequent treatment such as washing or cleaning.

In general, the producing of sand may be divided into the following five steps: Stripping, digging or excavating proper, transporting, treating, and shipping.

STRIPPING OF OVERBURDEN

Stripping may be done by hand, drag scrapers, or steam shovels depending upon the thickness of the overburden and the size of the working. Small wayside pits have practically been abandoned in favor of large efficiently equipped plants for the production of structural sand. This change has been brought about by the insistence of engineers and builders upon the use of tested sands, as well as the decreased cost of production when operations may be conducted on a large scale. When good grades of suitable material are readily obtainable near at hand, local producers still get large amounts of sand from small pits.

Frequently it is possible to use the overburden as fill for the excavated deposits. If possible filling is always advisable as it eliminates the expense of transporting the overburden and finding a place for its disposal. Because molding sand is usually found under an overburden of soil thereby underlying agriculturally valuable land, the overburden of soil must be replaced after the molding sand is removed. This is accomplished by opening a long pit and removing the sand along the whole length of the pit before a new cut is made. The overburden is removed by hand-shoveling and thrown back into the bottom of the worked out pits. The average thickness of overburden of this kind is not more than about a foot and the thickness of the molding sand layer seldom exceeds two or three feet in Michigan.

In the case of core sand the soil overburden is very thin, and the land is generally of no agricultural value so that it is customary in many core sand pits to remove the entire deposit from the surface down and pass overburden and sand through the screens which are relied upon to remove whatever sticks and grass may have been picked up by the scrapers or by the small power shovel.

EXCAVATION

In extensive workings the sand is generally excavated and loaded with steam or electric shovels in cars of the industrial or standard railway type. This method of operation demands a fairly thick bank, or bed, of sand of considerable horizontal extent and a comparatively dry floor on which the shovel may travel.

If the sand is wet or is obtained from river bottoms or bars, a drag line or some form of dredge will take the place of the steam shovel. Suction dredges have proved satisfactory in excavating under-water deposits where the proportion of gravel to sand is low and the pebbles are not too large to be pumped successfully. Otherwise some form of ladder or bucket dredge is generally used.[1]

The power shovel is a flexible unit which can be readily moved to different parts of the base of the deposit, if the quality is variable, to load the desired grade. It also has the advantages of handling large boulders and coarse gravel. Although railroad type shovels are occasionally used, the revolving type mounted on caterpillar trucks are more flexible and eliminate the laying of heavy planking or rails.

In some of the smaller workings, horse drawn scrapers are used to recover the sand and transport it to the shipping or treating station. It is necessary to resort to scrapers or hand digging if the deposit is relatively thin.

Core sand will not bear the expense of hand digging. For this reason core sand is usually recovered by means of horse drawn scrapers, or by some mechanical diggers such as a small steam or gasoline shovel.

In recovering molding or naturally bonded sand, hand shovelling is necessary in most cases because of the need for rather accurate selection of the parts of the section to be included. The use of scrapers in stripping or removing the overburden is uncommon as the sand surface must be finally cleaned of the overburden by hand shovelling and because the overburden is generally spread evenly over the floor of the excavated part of the pit in order that the agricultural value of the land may be retained. If the molding sand deposit is very uniform, it is possible to adapt some mechanical digger for recovering the sand. Under these conditions the use of a small steam shovel for thick sections of uniform sand is entirely possible. The use of a machine commonly used for digging ditches has proved satisfactory in a number of cases in which the machine is run up and down along the face of the bank.

The sand dug by any of the methods described above must be cleaned to remove pieces of wood, whatever large stones may have been picked up, and any pieces of metal that may be included in the sand. In the case of structural and core sand this is frequently the only treatment it receives before being loaded on cars for transportation to the market or foundry.

[1]W. M. Weigel, Technology and Uses of Silica and Sand, U. S. Dept. of Commerce, Bureau of Mines, Bulletin 266, 1927.

TRANSPORTATION

In the pit operated by Fred Black at Juniata, Tuscola County, the sand is recovered by horse drawn scrapers which are dragged up an incline and dumped into a hopper which feeds a belt carrying the sand rotary screen over the flat car in which the sand is loaded. The belt conveyor and rotary screen are driven by a Ford motor which is the only power equipment required.

Folding sand is usually shoveled into carts and drawn to the screens, or in some cases loaded directly into the trucks.

In some of the larger pits such as that of the Rochester Sand and Brick Company, Oakland County, a steam shovel is used to load a number of small cars on a narrow gauge track which are drawn by horse power or a small gasoline engine to the cleaning and screening plant from which the sand is dumped into the railroad cars.

TREATING

In recovering molding sand it is frequently necessary to mix different amounts of the heavy or highly bonded sand found near the upper part of the deposit with the sharp unbonded sand found below, in order to supply the different bonded sands demanded by different purchasers. Adequate mixing demands that before being loaded into the freight car the sand be mulled or passed through roll crushers after the desired proportion of the heavy sand and the sharp sand is loaded into small wagons or wheelbarrows.

MIXING

Mixing is usually done by loading the desired amounts of sand from the two different sections on the same cart and depending upon mulling and screening to complete the mixing during loading. Although this mixing of molding sand from two different sections of the deposit or from two different deposits in the same district may develop certain desirable properties in the mixed sand, generally the gain in one physical property is certain to be attended by the loss in some other desirable physical property. It seems that whenever mixing must be done it can be done to better advantage by the foundryman than by the producer of the sand, because the foundryman has the immediate objective of the mixing in view.

The manner in which the sand is handled in the pit, may have a very marked influence on the quality of the sand shipped. Occasionally some of the overburden, particularly if it is clayey, is mixed with the sand to increase the bond. This practice may introduce considerable silt or extremely fine sand with the clay, particularly if the clay is water laid or wind-blown material, and not a product of decomposition of the sand particles. The silt has no use or purpose in the molding sand, except in those sands used for very small castings. In this case high permeability to the gases given off during casting and high strength of the sand are not necessary as the castings are small and light and do not generate large volumes of gas. In molding

sands to be used for more exacting purposes, the silt simply clogs up the pores in the sand, preventing free escape of the gases and does not contribute to the strength or bond in the molding sand.

On the other hand, it is customary to mix sharp sand or clean unbonded sand with the heavy bonded sand to produce what is known as a lighter molding sand. In this mixing process the chances are that the clay does not become properly bonded with the sharp sand because the colloidal conditions necessary for the development of its full bond strength do not exist. Mixing of sharp sand under these conditions would tend to increase the permeability of the sand but also to greatly weaken its bond or strength.

WASHING

In preparing structural sand for the market it is frequently necessary to wash the sand to remove most of the clay and silt. The simplest washing method is to excavate the sand by pumps and discharge the wet sand into bins or scows. Passage through the pump and pipe line tends to scour the sand and break up lumps, and the water overflowing from the bins or hoppers carries away the excess clay and silt. Regulation of the depth of water between the overflow and the sand allows the amount of very fine sand remaining to be controlled[2] to a limited extent.

If the sand contains over-size material which must be removed or foreign substances such as roots or pieces of buried wood, the sand must be screened before it may be washed. Very few sands are clean or uniform enough to need no screening.

[2]Edmund Shaw, The Design of Sand Plant, Rock Products, 25, page 89, December 30, 1922.

SCREENING

Stationary screens must be given enough slope to clear themselves of over-size. Shaking or oscillating screens need have relatively only a slight slope.

Revolving cylindrical screens in which the axis is placed on a slight angle from the horizontal so that the material will constantly move forward, and conical screens in which the shaft may be horizontal, the slope being obtained by the angle of the cone, are found in many pits. Increasing the slope of these screens spreads out the material in a thinner layer and passage of the fines through the screen is more rapid.

Sand, or gravel and sand, in which the percentage of gravel is low cannot be screened efficiently on stationary screens. For material of this kind the vibrating screens are generally considered more successful. Shaw[3] describes the use of the various types of screens in detail.

Stationary screens may be kept at such an angle with the horizontal to give the most screening with the least tendency to blending. The pitch varies with the kind of fabric used, size and nature of the material to be screened. The apertures of the screen should be slots and not round or square holes, the length of the slot being in the direction of travel of the grain. This allows for the trajectory of the grain. The screen area should be much greater for the fine mesh than for the coarse mesh screen. Short and wide screens are much more efficient than long and narrow screens. To do the best work the long narrow screens should be broken up into sets of short wide screens with baffles to check the speed of the grain.

Revolving screens of the ordinary conical and cylindrical forms are specially adapted to washing plants, as it is not only a good screen but a good washer and scrubber as well. For large screens with heavy duties, the trunion type of the cylindrical screen is the best. Screens with central shafts and spiders are preferred to lighter screens with ordinary duty. The slope of the revolving screen is important, a common error being to set them with too little slope. Generally the best slope is from ten to fourteen degrees or two to three inches per foot. The correct speed is equally important and poor work can be sometimes bettered by increasing or decreasing the speed of rotation.

Generally, revolving screens are used in washing plants, as revolving screens are always to be preferred with limited amounts of water. Stationary screens may be used if accompanied by plenty of water and fine screening is not desired.

The electric vibrating screens seem to be preferred for fine screening. If electric current is not available there is a wide range of screens which are agitated by mechanical means.

In some installations sizing of the sand is accomplished in settling tanks. Tanks do not size sand as positively as screens but their initial cost is low, and, requiring no power and few repairs, are economical when satisfactory results can be obtained by this method. All washed sand, or sand that has been settled by hydraulic means, requires to be de-watered or dried before shipment.

[3]Shaw, Screens for Washing Plants, Rock Products, 25, page 18, October 21, 1922, page 32, November 4, 1922, page 15, November 18, 1922, and page 17, December 2, 1922.

DRYING

Drying is frequently accomplished in a Lewiston type of steam dryer but there seems to be a tendency in the newer plants to use rotary driers fired by coal or oil. The direct fire driers are without doubt better regarding fuel efficiency, but steam driers may have the advantage of keeping the sand clean and freer from contamination.

Steam driers usually consist of a brick bin with a V-shaped or hoppered bottom discharging onto a belt conveyor. Running lengthwise of the bin are tiers of pipes supported on steel angles through which live steam is circulated. The usual arrangement from the top down, is about seven tiers of two-inch pipes below which at the bottom are two tiers of one inch pipes, staggered and placed close together. The top of the drier is opened and forms a hopper into which the wet sand is

discharged. In practice the wet sand is piled upon the pipes covering them completely. As the sand dries, it falls down between the pipes into the hopper and is discharged onto the conveyor. Circulation of air is maintained through the drier by an exhaust fan connected to an exhaust pipe near the top of the drier on one side. The dimensions of these driers are usually about eight feet wide and six to eight feet high above the hopper bottom, with lengths up to about sixty feet. Each drier section, about twenty feet long, is usually estimated to have a capacity of about two hundred to three hundred tons of sand for twenty-four hours. The dry sand usually contains ten percent, or slightly more, of moisture.

SHIPPING

Shipments of the lower grade sands, such as the structural and foundry sands, are usually made in open cars. As these sands have not been especially prepared or dried, little damage is done by exposing them to the elements in shipping. However, rains sometimes have a tendency to wash the clay from the molding sand, particularly if exposed for an appreciable time. Such sands as glass sand, which are carefully prepared and dried, are almost invariably shipped in box cars.

Chapter III. CHEMICAL PROPERTIES

Although the physical properties of foundry sand are far more important from all considerations than the chemical properties, the latter must be considered because of their importance in determining the physical properties of the sand. In the final analysis all physical properties may be regarded as outward evidence of chemical conditions existing in the sand.

MINERALS IN SAND

The result of a thorough investigation into the mineral composition of sands[1] identified a large number of minerals. Among those found, the following should be mentioned:

QUARTZ

Quartz ($S.O_2$) is one of the most abundant minerals occurring in nature. Its hardness, insolubility, and lack of cleavage render quartz almost indestructible, and make it the main constituent of sand and gravel.

The principal source of quartz is granite and other igneous and metamorphic rocks, in the formation of which quartz is the last constituent to crystallize during cooling. For this reason quartz grains frequently contain inclusions of minerals that solidified earlier. Hair-like rutile crystals, rods of apatite, and dust particles of other minerals are common and can be readily seen under the microscope. Liquid and gas inclusions are also characteristic of quartz.

Surface water may leach out these soluble inclusions in the quartz, which thereby afford a means for the disruption of otherwise almost indestructible quartz crystals.

If the sand has been formed by weathering of rock in place, the grains are generally angular. In sedimentary deposits, which are generally used in the northern states for sand, the grain has become rounded by being rolled and ground while washed along the stream or by the waves on the beach before being deposited in more quiet water.

Quartz has a hardness of 7, being harder than glass which varies from about 4.5 to about 6.5.

[1]Dale Condit, Transactions of the American Foundrymen's Assn. Vol. 21, pages 21-27.

FELDSPAR

The *feldspars* occur in different crystal forms and of different compositions. They are all complex aluminum silicates with calcium, sodium, or potassium silicates. *Orthoclase* $KAlSi_3O_8$, and microline having the same composition are two different crystalline forms of the same chemical compound. *Plagioclase feldspars*, mixtures of albite, the sodium aluminum silicates, with anorthite, are identified as *oligoclase* and *labradorite*.

The feldspars are probably next to quartz in abundance and distribution in sands. They have a prominent cleavage in two directions inclined at or near 90°. The color of feldspar varies from white, to pink, to gray. In sand, grains of feldspar are often seen that are made up of alternating layers of orthoclase and plagioclase.

Feldspar exposed to weathering in a moist climate undergoes relatively rapid decomposition; the potash, soda and lime bases being leached out, leaving kaolinite, the aluminum silicate which forms the basis of clay. Feldspar fuses at a temperature of about 310 degrees C. corresponding to Cone 9, but different species vary greatly in this property, those containing lime and soda fusing at lower temperatures than the orthoclase. Feldspar is softer than quartz, and is more readily broken down by solution or chemical action.

MICA

Mica exists in a number of species of rather complex compositions, of aluminum silicate with other bases.

Muscovite or white mica has a formula corresponding to $H_3KAl_3(SiO_4)$ and occurs in glassy plates which are fairly resistant to decomposition by weathering. For this reason the thin scaly particles of muscovite are frequently evident in sand. *Biotite or black mica* is a complex silicate containing potash, and magnesia or iron, with the aluminum silicates common in all mica. Biotite is seldom found in molding sand as it readily alters to chlorite and limonite on weathering. All micas tend to lower the refractory quality of sand and for this reason are generally disadvantageous.

AMPHIBOLES

Amphibole. This group of variable composition, includes *hornblende*, *actinolite*, and *tremolite*, as in the more common varieties. They are all silicates of magnesium, iron, aluminum and lime.

As fusion is not difficult, the presence of the compounds tend to lower the fusing point of the sand which is not then good for heavy work.

PYROXENE

The pyroxene series is similar to the amphibole series in chemical composition, and has much the same properties of fusion, and ease of weathering, so that they are not common except in recent sands derived from glacial drift. The series include *diopside*, a silicate of lime and magnesia, *augite*, a complex silicate containing lime and alumina, enstatite, and hypersthene, which are silicates of magnesia and iron.

IRON

Iron is present in sand in a large number of minerals. In addition to those mentioned above, in which iron is found as a part of a complex silicate, the following minerals containing iron without the presence of other metals may be considered as a group:

Magnetite (Fe_3O_4 or Fe_2O_3FeO) is the black magnetic oxide of iron. This oxide does not weather readily when exposed to water, but when acted upon by organic acids it decomposes to hematite and limonite. Magnetite is common in sands and in many molding sands. It is present in recent sands either as free grains or as inclusions in other minerals,

Ilmenite ($FeTiO_3$) is a black magnetic oxide of iron and titanium and is a common associate of magnetite in sands. It is very refractory and is used in the preparation of linings of puddling furnaces.

Hematite (Fe_2O_3) is the red oxide of iron. Both hematite and magnetite have a hardness of about 6 on Moh's scale.[2] Although hematite itself is very refractory, when present in large amounts in molding sand and used in the presence of excess iron which is poured into the mold, the iron oxides are frequently reduced to the ferrous condition in which form they slag readily with other minerals, particularly silicates which are always present in sand. For this reason a high iron content in the sand may in some cases cause the sand to fuse and stick to the casting, particularly if the casting is poured at a fairly high temperature.

Like magnetite, hematite is readily dissolved in water containing organic acids. As the water percolates down through the sand, the iron is precipitated as a hydrated oxide, *limonite*, on the sand grains. Apparently this precipitate is largely colloidal in nature due to the protective action of the organic acids. It seems that the presence of limonite deposited in this way on the surface of the sand grains is an important factor in developing a durable bond in the molding sand. The grains of most high grade molding sands are rather thickly coated with limonite in a colloidal condition.

Limonite is the hydrated ferric oxide formed by the solution and hydration of magnetite or hematite. It is yellow brown in color and reverts back to the dehydrated form, hematite, when heated to reasonably high temperatures. It is this action which explains the red character of the molding sands[3] found in England wherever they have been exposed to volcanic action. The same change in color from yellow or brown to red upon heating of American sands has been noted.

Siderite ($FeCO_2$) or iron carbonate, weathers to limonite in much the same way as hematite except that oxidation as well as hydration is involved. Because of the ease of weathering of siderite it is seldom found in sand deposits. It is frequently observed in a deeper, blue layer of clay in a clay bed. As weathering of clay proceeds more slowly than the weathering of sand, because of the open structure of the sand which allows free passage of water and oxygen, siderite is seldom found in molding sands. The color of this blue clay, frequently erroneously called "fire clay", underlying the red clay which has been weathered near the surface, is usually due to the presence of siderite which has not yet been converted into limonite.

Pyrite (FeS_2), the iron sulphide, has a yellow metallic luster ("fool's gold"), is readily weathered by hydration and oxidation to the sulphate or to limonite. For this reason pyrite is not common in sand derived from surface deposits but is frequently found in the deeper workings of quarries.

[2] A scale of hardness with a diamond 10, corundum 9, topax 8, quartz 7, orthoclase 6, apatite 5. fluorite 4, calcite 3, gypsum 2, talc 1.

[3] Fletcher loc. cit. see Chapter 1.

CALCITE

Calcium carbonate ($Ca\ CO_3$) or limestone is frequently found as small particles in sand derived from glacial drift, or in recent deposits of sand in glacial outwash, or deposits which have not been thoroughly weathered or leached. It has a hardness of three and a specific gravity of about 2.72. It is generally colorless, white, or amber, with a vitreous or glassy lustre. It dissolves readily in weak acids and is rapidly weathered by surface waters particularly those containing carbon dioxide. Lime acts as a fluxing agent, and is undesirable in sands used for many purposes as well as in foundry sands. It not only tends to lower the fusing point of the sand, but in case of core sand it reacts frequently with the core oils used to create the bond in forming the cores. It also seems to have a deleterious action on the durability of the bond in molding sands.

Dolomite is a calcium magnesium carbonate ($CaMgCO_3$) slightly harder and heavier than calcite and is less readily soluble in water and weak acids.

Magnesite ($MgCO_3$). Magnesium carbonate, is very similar to dolomite, being somewhat harder, 4 to 5, on Moh's scale and with a specific gravity of about 3.1.

Gypsum ($CaSo_4H_2O$) is hydrated calcium sulphate and may be found in recent sands or clays which have not been exposed to thorough weathering.

CLAY

In addition to these minerals mentioned above which are found strictly as grains in the sand, or on the sand particles, we have a large group of hydrous aluminum silicates which represent the clay present in the sand. These minerals are always of secondary origin, in most cases probably derived from feldspar, or other similar minerals. Because of the importance of the hydrous aluminum silicates in forming the bond in molding sands, the following should be mentioned:

Kaolinite ($H_4Al_2Si_2O_9$ or $Al_2O_32SiO_22H_2O$), corresponds to a composition of silica (SiO_2) 46.6 percent; alumina (Al_2O_3) 39.8 percent; water (H_2O) 13.9 percent. It is soluble in hot sulphuric acid and in sodium carbonate. When wet it is slightly plastic. It is pearly white, and crystallizes in the monoclinic system in small hexagonal plates with a hardness of 2-2.5 (Moh's scale) and a specific gravity of 2.2-2.6. Its index of refraction (1.56) is the same as that of *Canadian balsam*, and its optical behavior is very similar to that of *muscovite* so that it can be distinguished from colorless mica only by analysis to prove the absence of alkali. When stained with methylene blue the crystals are lamellar and exhibit a zonal structure parallel to the edge.

Kaolinite is always of secondary origin, in most cases probably derived from feldspar. Although chemically possible, its derivation from minerals other than feldspar has never been proved. It may be formed from feldspar according to the equation:

$$2KAlSi_3O_8+2H_2O+CO_2=H_4Al_2Si_2O_9+K_2CO_3+4SiO_2.$$

Pure kaolinite is very refractory but a small addition of impurity decreases its refractory properties.

Halloysite is closely related to kaolinite, having the same relative amounts of alumina and silica but a greater amount of water, and an amorphous structure. Halloysite is massive, like clay, has a conchoidal fracture, and shows little or no plasticity. Its hardness is 1 to 2 and specific gravity 2.0 to 2.20. Its color is white, frequently with a gray, green, yellow or red cast, with a pearly luster to waxy dull. When placed in water it swells and falls to a powder. It is translucent to opaque, sometimes being even transparent in water with an increase of one-fifth in weight.

Halloysite found in a deposit five miles southwest of Aurora, Missouri, and somewhat stained by yellow clay fused completely at cone 15 (2600 degrees F.) and has the following composition:

Silica (SiO_2)	44.12%
Alumina (Al_2O_3)	37.02
Ferric Oxide (Fe_2O_3)	.33
Lime (CaO)	.19
Alkalies (Na_2O K_2)	.24
Water (H_2O)	18.48

which agrees closely with the theoretical composition as given.

Other less important minerals or mineral substances found in sand are tourmaline, zircon, apatite, rutile, garnet, corundum, chlorite, serpentine, epidote, spinel, indianite, pholerite, allophane, rectorite, newtonite, pyrophyllite, etc. Some are complex silicates and others are oxides. Several of the last mentioned above are hydrated. The combined water in these hydrated minerals does not evaporate on drying, but is driven off as steam only at relatively high temperatures, usually about 650-750 degrees C.

SIGNIFICANCE OF COLOR

In most sands weathering has proceeded to such an extent that only those minerals which resisted weathering to relatively high degree are left. Quartz, being practically unaffected by the ordinary agents of weathering, is by far the most abundant mineral in sands used for foundry purposes, constituting in most cases 50 to 70 percent of the entire content. Color is of importance in indicating the nature of the accessory minerals. The white molding sands have, in addition to quartz, such minerals as feldspar, mica, calcite, dolomite, and hydrous aluminum silicates. The carbonates—calcite, and dolomite,—show distinct cleavage and effervesce in hydrochloric acid. Mica has a flaky characteristic silvery appearance. The feldspars are generally partially or completely altered into hydrous aluminum silicates.

Olive green or bluish green coloring is usually due to the presence of ferrous magnesian minerals and their alteration or decomposition products of which chlorite and serpentine and the hydrated magnesium silicates are the most common. Their derivation is chiefly by alteration of olivene, amphibole, pyroxene, epidote, and biotite.

Rusty yellow, reddish brown and chocolate colors in the sand are due to iron oxide. Generally, the yellow reddish sands are considered best for molding purposes as the presence of colloidal iron oxides on the surface of sand grains seems to indicate the desirable bonding properties in natural-bonded sands.

CHEMICAL COMPOSITION OF SAND

The oxides determined in sand analysis may serve to give some idea concerning the fusibility of the sand, and, suggest some of the minerals which may be present. But, in general, a chemical analysis of sand is of far less value than direct tests of its physical properties, as the physical properties are those that determine the actual value of the sand, and it is much better to determine the

desirable properties directly than to try to estimate them by indirect means as through chemical analysis. In the ultimate analysis of sand the following oxides are usually determined:

SILICA

Silica is the most important oxide and practically all of it is supplied by either quartz grains or by the hydrous aluminum silicates in the clay, the rest of the silica being accounted for by mica, or feldspar.

ALUMINA AND IRON

Alumina is present in the clay or to a slight degree in amphibole, pyroxene or *mica*, when present. *Iron* is usually present as oxides in the form of limonite, hematite or possibly magnetite or siderite. There is also a small amount of iron in other minerals such as chlorite, epidote, and some varieties of amphibole, and tourmaline.

LIME

Lime or calcium oxide enters into the makeup of a number of the minerals, principally the calcite, dolomite, and some of the feldspars. Many of the Michigan sands contain relatively large amounts of lime, indicating that they are only recently derived from the glacial deposits, as weathering would tend to leach out the lime.

ALKALIES

The *alkalies*, soda and potash, may be present in the micas, and in sands recently derived from glacial drift in undecomposed feldspars.

SULPHUR

Sulphur is usually present only in very small amounts and may be due to pyrite or to some sulphate.

WATER

Water is almost universally present as moisture, but may also be present in the hydrated minerals, particularly the hydrated aluminum silicates making up the clay substance in the molding sand. The hydrated iron oxide, limonite, chlorite and moscovite, mica, also have water in chemical combination which is given off on ignition.

ANALYSES OF SAND

Hanley and Simons give analyses of typical sands used in foundry work as in Table I.

	Medium Molding Sand	Coarse Core Sand	Facing Sand	Fire Sand	Gravel	High Silica Steel Sand	Parting
	%	%	%	%	%	%	%
Loss on Ignition	3.05	.75	2.00	1.14	1.34	.45	.45
Silica (SiO_2)	82.10	95.25	88.52	94.00	84.18	97.55	98.01
Iron Oxide (Fe_2O_3)	5.23	1.45	5.69	2.15	3.02	1.00	.30
Aluminum Oxide (Al_2O_3)	7.70	.50	2.47	2.45	7.95	.61	.85
Calcium Oxide (CaO)	.63	1.01	Trace	Trace	.44	.15	.10
Magnesium Oxide (MgO)	.13	.42	.23	.08	.37	.21	.06
Sodium Oxide (Na_2O)	Trace	.15	.06	Trace	.07	Trace	Trace
Potassium Oxide (K_2O)	1.15	.10	.85	.05	2.51	Trace	Trace

*Foundry, Vol. 48, p. 742.

Table I. Chemical Analyses of Typical Sands.

RATIONAL ANALYSIS

Rational analysis a method for conducting a rational analysis of molding sand has been outlined by Field.[4] In this method, the sand is regarded as being composed of quartz, feldspar and clay substance. The method of analysis consists of digesting one gram of sand previously ground to one hundred mesh and dried at 100 degrees C. for one hour with sulphuric acid for a period of about twelve hours. It is then filtered.

The filtrate, containing the sulphuric acid solution and carrying the iron and alumina of the clay substance, is oxidized with bromine and precipitated with ammonia to determine the amount of iron and alumina in the clay substance.

Region	No. of Samples	Quartz Percent	Clay Substance Percent	Feldspar Percent
Albany	23	58.82	18.99	22.16
Kentucky	13	64.53	24.77	10.69
Ohio	14	71.02	23.79	5.17
New Jersey	4	81.38	15.49	3.13
Pennsylvania	9	67.21	21.99	10.79
Missouri	10	64.10	24.36	11.54
Illinois	1	70.82	16.65	12.53
Georgia	1	77.37	17.94	4.69
Tennessee	1	74.53	21.11	4.36
American Average		65.53	21.73	12.74
French sand, Paris region		84.45	10.68	4.69
German Sands:				
Bransenberg		87.31	10.19	2.50
Freyunwalde		58.63	15.77	25.23
Luneburg		85.72	7.71	6.89
Hanover		86.57	7.52	6.44
British Sands:				
Workshop		74.01	12.60	8.88
Mansfield		73.36	5.90	12.39
Erith		73.47	14.48	11.40
Kiddemaster		74.40	7.71	13.28
Stourbridge		64.76	10.53	23.46
South Staffordshire		77.21	6.99	13.03
Clyde		78.23	7.03	12.80
Glasgow		89.47	4.70	4.18
Wordsley		73.34	11.76	11.12

[4]Moldenke, Principles of Iron Founding, p. 285.

Table II. Rational analysis of Molding Sands.

The precipitate is then digested with a ten percent solution of sodium hydroxide solution, filtered, washed with water, then with 1 to 3 hydrochloric acid, and again with water until the filtrate is free from chlorites. The residue after being ignited to constant weight in a platinum crucible, represents the weight of quartz plus feldspar. This weight subtracted I from the original weight of the sample gives the weight of the clay substance. The quartz plus feldspar residue is then fused with five times its weight of sodium carbonate in a platinum crucible to determine the alumina present. The alumina determined in this way represents the alumina of the feldspar, which can then be calculated on the assumption of the formula for feldspar Al_2O_3, K_2O, SiO_4 which has an alumina content of 18.34.

Analyses made in this way on a number of sands showed quartz varying from 45 to about 88 percent, usually between about 78 percent and 67 percent. The clay substance was found to vary from about 9 to about 12 percent usually between the limit of 13 and 30. Feldspar varies from 2.5 to 30 percent

An average of the rational analyses of the sands from various parts of country and Europe may be of interest in indicating the results of this method of analyzing sands.[5]

A glance at the figures given in the table above shows that there are wide variations in the composition of

molding sands. Decomposed feldspar, which is fusible at high temperatures such as exist when iron is molten, as computed from this method of rational analysis runs as high as 22.16 percent in the Albany sands. This fact may account for the almost universal use of the Albany sands for light work in which the iron sets almost as poured, and hence the fusibility of the feldspar has no chance to come into play.

In order to see if the grain size had any effect on the rational analysis of the sand, samples were classified into three groups: fine sand, more than 90 percent smaller than 100 mesh; medium sand, 80 to 90 percent smaller than 100 mesh; and coarse sand, less than 80 percent under 100 mesh. A tabulation of the quartz, clay substance and feldspar throughout these three different size classifications indicates that, with few exceptions, whether a sand be coarse or fine, it seems to carry the same proportion of these materials, depending only upon the deposit from which was obtained.

[4]Transaction of the American Foundrymen's Association, Vol. 21, page 85.

[5]Moldenke, Transactions of the American Foundrymen's Association, Vol. 28, page 692.

COLLOIDAL MATERIAL

The importance of colloidal material in natural bonded molding sands is generally recognized. There can be little doubt but that the natural bond in sand is due largely to a colloidal or a surface condition of the sand particles in relation to the "clay substance", which is a general term used by foundrymen to include all of the very fine particles and various colloidal oxides as well as clay.

The presence of water is necessary for the proper development of the bond strength in molding sand, and it is also necessary to the development of the colloidal condition, either as a hydrosol or as a hydro-jell. Heating these colloids dehydrates them and in many cases causes some change in their structure which prevents the later absorption of water and the reforming of the original colloid. Heating the sand to high temperatures also destroys the natural bond. A careful study of the colloids contained in natural bonded molding sands and the relation existing between these colloids and the bond, is of fundamental importance to an understanding and accurate knowledge of molding sand.

In the last analysis colloid is probably a physical condition of a chemical substance, and is therefore, on the border line between a chemical property and a physical property.

Determination. Methods of determining the amounts of colloids in molding sands have not been sufficiently developed to give any certain degree of accuracy. Physical tests such as measurement of bond strength, or compression tests, are neither accurate nor direct measures of colloidal matter, but are simply the measurements of the physical properties, which are assumed to be dependent upon the colloidal matter in the sand.

Eighteen possible methods under eight distinct headings have been listed for measuring the colloidal contents of soils. The fact that so many different methods have been proposed indicates that no satisfactory test exists for this purpose. Of all these methods[7] the dye adsorption test is frequently considered the best. Many investigators object to the use of the *dye adsorption test* as a measure of colloidal matter, because, being an equilibrium reaction the result depends on the amount of surface of the sand exposed and the concentration of the dye in solution just as much as upon the colloidal matter present.[8]

It seems that the dye adsorption test might indicate difference in the amount of colloids present in a given particular sand, as changes brought about by heating. The surface of the sand itself, under these conditions would remain practically constant but the surface of the colloid would change markedly, as the dehydration caused by the heating would cause the colloids to contract and prevent them from adsorbing the amount of moisture originally contained in the hydro-sols and the hydro-jells of the sand.

Work done by William M. Saunders and reported by C. M. Nevin[9] in which this method of determining the presence of colloid matter in various sands was used, seems to indicate that the dye-adsorption test may be used with satisfactory results to indicate the destruction of colloidal matter in a given sand when heated to different temperatures under different conditions. But in using the dye-adsorption test to determine the presence of colloid in sands of different grain size and from different deposits, inherent limitations in this method must be kept in mind if accurate conclusions are to be drawn from the results of the test.

[7]Estimation of Colloidal Material in Soils by Adsorption, U. S. Department Agriculture Bulletin, 1193, 1924.

[8]C. M. Nevin, Transactions of the American Foundrymen's Association, Vol. 33, page 763.

[9]Transactions of the American Foundrymen's Association, Vol. 33, page 793.

Chapter IV. PHYSICAL PROPERTIES

The economic value of a sand depends upon its physical properties. The physical properties which are of value in evaluating sands depend in large measure upon the uses to which the sand is to be subjected. However, there are a number of tests which are used to determine the most important physical properties for all purposes. These tests are of general value, and a number of them are recognized as standard tests.

TEXTURE OR FINENESS

Fineness or texture of the sand is its most important single property, not only in itself, but also because

texture determines to a large extent the degree of the other important physical properties. For this reason, sands are usually classified according to the fineness of the constituent particles. This customary classification of foundry sands is also based on the fact that a coarse sand when molded gives a surface of much coarser texture than does a fine sand. In this way the surface of the resulting casting is dependent very largely upon the texture or fineness of the molding sand used. This same relation also applies to core sands and other sands.

This difference in the texture of the sand is readily recognized without making any special tests and is determined by experienced molders from their sense of touch. This practice has given rise to the term "*relative fineness*" which does not recognize differences in the size distribution of the particles but simply the general fineness or coarseness of the sand.

The degree of sorting or the *size distribution* of the constituent grains or particles of the sand may differ greatly in sands which seem to the eye and hand to be of the same relative degree of fineness. Such variations in the size distribution of the particles affects the permeability and the bond strength to a considerable extent but in itself does not generally affect the suitability of molding sands for a given use. Because this fact has not been generally recognized in the past, particularly by the practical foundrymen, the belief has arisen that every molding sand is a law unto itself and that scientific methods of control are difficult of application.

Recognition, however, of the fundamental factors determining the important physical properties of molding sand clearly indicates the importance of determining size distribution as well as relative fineness. If sands of spherical particles are perfectly sorted into uniformly sized grains the void in the sand is independent of the grain size. However, if the size distribution is not uniform the percent of void will in no case be constant, as small particles contained in a sand composed of large trains tend to fill up the void space between the large grains.

METHODS OF DETERMINING FINENESS OR TEXTURE

The sense of touch is reasonably accurate when applied to the determination of the relative fineness of sand, very little experience is necessary to enable one to distinguish correctly between sands differing slightly in fineness grades when the sands are placed side by side for direct comparison. But it requires long and continuous experience to develop anything approaching accuracy in judging the absolute fineness of sands and it is impossible to convey this individual experience to others. It is essential that some more finite method of determining absolute fineness be applied in order that the fineness scale shall be fixed or stabilized for it to become generally useful.[1]

The Albany Grading Scale originally depended solely upon the sense of touch and is still in effect upon this basis, with little evidence of being superseded by any other method. In spite of its crude basis the Albany Grading Scale is quite definite to those few individuals of long experience who supervise the production and loading of the major portion of the Albany sand. The scale becomes less and less definite, however, as the sands are removed from these supervisors until at the extreme end of the handlers among the foundrymen the scale is rather hazily indefinite.

Hansen has shown that this method of grading sands on the basis of size bears a direct relation to the size of the sand particles determined by screen analysis, which is the only commonly accepted scientific method of determining the fineness, and size distribution of sand.

Screen Analysis

Rittinger Series: The fundamental basis upon which American Standard Testing Screens were designed was originally proposed by Professor Rittinger,[2] about 1868. The Rittinger series represents a geometric series in the area of the rectangular spaces between the woven wires constituting the screens, such that the area of any one opening was twice that of the next finer one in the series, or the distance between wires composing the mesh vary in the successive screens as the square root of two, or 1.414.

Later Professor R. H. Richards proposed a similar geometric series containing twice this number of screens, in which the ratio between the sieve openings was the 4th root of 2 or 1.189. This series is sometimes referred to as a *double Rittinger ratio*, and has the advantage of providing an increased number of sieves particularly in the finer sizes.

[1]C. A. Hansen, The Grading of Molding Sand, Transactions of the American Foundrymen's Association, Vol. 24, page 375.

[2]Proceedings the A. S. T. M., Vol. 13, 1913, page 1068.

If the screens are carefully selected and carefully used the single Rittinger ratio series is amply accurate for most practical purposes. Screens, however, are frequently abused in such a manner as to destroy the initially uniform weaves, and when this uniformity of weave is destroyed the screens are very far from being efficient tools. The greater the number of screens, the less important becomes one or more inaccurate screens in the series. Furthermore, the inaccurate screens are conspicuously indicated in the results obtained, so that they can be weeded out and discarded. For these reasons, the Richard Series based on the ratio of the 4th root of 2 is generally preferable in making analyses of fineness of sands.

Mesh: Although the area of the opening in the wire mesh is the determining factor in sizing, unfortunately the sizes of the various screens have become known in terms of mesh, or the number of openings per linear inch, which bears no direct relationship to the size of the opening unless the size of the wire used in weaving the screen is also specified. As there are at least two important series of testing screens using different sized

wire for the same screen openings, this custom of referring to size of materials in terms of mesh has caused needless confusion.

If we follow the suggestion of Hansen[3] and substitute for the conventional *mesh* as designating the size of the screen, a series of serial numbers constituting a rationally uniform scale on which the serial numbers in arithmetical progression represent the area of the openings in the screens taken in geometric progression, these apparent differences in the screen series disappear. Table III indicates that a serial number, as given in the first column with the corresponding opening in the screen reported in the second column in inches, is, according to the double Rittinger or Richard's series, based upon the fourth root of 2. The succeeding columns three and five, give the corresponding number of the screen and actual aperture in the Tyler Series, and columns four and six give the corresponding screen number and aperture in the Bureau of Standard Series.

A.S.T.M. Method of Mechanical Analysis. The American Society for Testing Materials method D, 7-27,[4] for making a screen analysis of sand for highway material, requires a representative test sample aggregate weighing fifty grams dried to constant weight at a temperature not exceeding 110° Centigrade, (230° F.). The sample is then passed through each of the following sieves from the Bureau Standards Series: 10, 20, 30, 40, 50, 80, 100, and 200 mesh. The percent by weight retained on each sieve is determined and the sieving on each sieve is to be continued until less than one percent of the weight retained on each sieve passes through the sieve during the last minute of sieving. The results so obtained are reported as percent passing 200, 100, 80, 50, - - - mesh.

The A.S.T.M. procedure for making sieve analysis for aggregates of concrete, C 41-24, is somewhat similar to the method described above.

N—(Rittinger Scale N)	Rittinger Formula Aperture Requirement in Inches, .00102 x 2^n	Corresponding Mesh (Linear)		Opening in Inches		Settling Rate in Water, Feet per Minute for largest Grains passing Tyler Screens
		Tyler Series	Bureau of Standards Series Nominal Mesh	Tyler Series	Bureau of Standards Series	
10.	1.04448	.....	.....	1.050	.....	.....
9.75	.877312	.....	.....	.883	.....	.....
9.5	.7384	.....	.....	.742	.....	.....
9.25	.62094328	.....	.....	.624	.....	.....
9.	.52224	.....	.....	.525	.....	.....
8.75	.438656	.....	.....	.441	.....	.....
8.5	.3692	.....	.....	.371	.....	.....
8.25	.31047104	2.5	2.5	.312	.315	.....
8.	.26112	3.	3.	.263	.265	.....
7.75	.219328	3.5	3.5	.221	.223	.....
7.5	.1846	4.	4.	.185	.187	1.002
7.25	.15523582	5.	5.	.156	.157	.....
7.	.13056	6.	6.	.131	.132	.872
6.75	.109664	7.	7.	.110	.111	.....
6.5	.0923	8.	8.	.093	.0937	.756
6.25	.07761792	9.	10.	.078	.0787	.....
6.	.06528	10.	12.	.065	.0661	.603
5.75	.054832	12.	14.	.055	.0555	.....
5.5	.046153	14.	16.	.046	.0469	.520
5.25	.03880896	16.	18.	.039	.0394	.....
5.	.03264	20.	20.	.0328	.0331	.408
4.75	.027416	24.	25.	.0276	.0280	.....
4.5	.0230765	28.	30.	.0232	.0232	.308
4.25	.01940448	32.	35.	.0195	.0197	.....
4.	.01632	35.	40.	.0164	.0165	.226
3.75	.013708	42.	45.	.0138	.0138	.....
3.5	.01153825	48.	50.	.0116	.0117	.164
3.25	.00970224	60.	60.	.0097	.0098	.....
3.	.00816	65.	70.	.0082	.0085	.114
2.75	.006854	80.	80.	.0069	.007	.....
2.5	.00576912	100.	100.	.0058	.0059	.0764
2.25	.00485112	115.	120.	.0049	.0049	.....
2.	.00408	150.	140.	.0041	.0041	.0496
1.75	.003427	170.	170.	.0035	.0035	.....
1.5	.00288456	200.	200.	.0029	.0029	.0310
1.25	.00242556	.....	230.	.....	.0024	.....
1.	.00204	.....	270.	.....	.0021	.0196
.75	.0017135	.....	325.	.....	.0017	.....
.5	.00144228	.....	.....	.....	.....	.0162
.25	.00121278	.....	.....	.....	.....	.....
.0	.00102	.....	.....	.....	.....	.0096

Table III. Comparison of Screen Sizes or "Mesh".

[3]Transactions of the American Foundrymen's Association, Vol. 34, page 376.

[4]A. S. T. M. Standards, 1927, Part II, page 479.

The A.F.A. Fineness Test. The methods for making screen analyses adopted as standard by the American Foundrymen's Association in December 1926, were used on the tests herein.

Procedure for Molding Sands Containing No Clay or Bonding Substance: One hundred grams of sand dried for at least one hour at a temperature of 105°C, with a tolerance of 5°C, are transferred to the first of a series of sieves, U. S. Bureau of Standards Nos. 6, 12, 20, 40, 70, 100, 140, 200 and 270[5] and placed in a RO-tap testing-sieve shaker. This machine is run for thirty minutes, and the amount of sand remaining on each sieve is weighed and expressed in percentage. The portion passing the No. 270 sieve is known as No. 270 minus.

5The fineness test may he graphically expressed by plotting sieve numbers as abscissa against the grain remaining on each sieve calculated as the percent of 50 grams.

Series of Sieves, U. S. Bureau of Standards

Sieve Number	Sieve Opening Millimeters	Sieve Opening Inches	Wire Diameter Millimeters	Wire Diameter Inches	Tolerance in Average Opening	Tolerance in Wire Diameter	Tolerance in Maximum Opening
6	3.36	.132	1.02	.040	±3%	+30%	10%
12	1.69	.0661	.69	.0272	±3%	30%	10%
20	.84	.0331	.42	.0165	5%	30%	25%
40	.42	.0165	.25	.0098	5%	30%	25%
70	.210	.0083	.140	.0055	6%	35%	40%
100	.149	.0059	.102	.0040	6%	35%	40%
140	.105	.0041	.074	.0029	8%	35%	60%
200	.074	.0029	.053	.0021	8%	35%	60%
270	.053	.0021	.041	.0016	8%	35%	60%

Procedure for Molding Sands Containing Clay or Bond Substance: Fifty grams[6] of molding sand, dried for at least one hour at a temperature 105°C, with a tolerance of 5°, are put into a standard one-quart preserving jar, having a smooth side with no sharp shoulders in the neck to prevent the sand from being easily removed with a small of stream of water. 475 cc water and 25 cc standard solution of sodium hydroxide (made by dissolving 10 grains of sodium hydroxide in 1,000 cc water) are added, and the jar filled to base of neck is covered and securely sealed. Instead of the usual rubber ring, a rubber disc is employed, which fits into the inside of the glass cover. The receptacle is then placed in a shaking machine, making about 60 revolutions per minute, in such manner as to allow it to be up-ended at each revolution. At the end of one hour the receptacle is removed, the cover unsealed, and the sand adhering to the cover is washed into the receptacle.[7] The receptacle is then filled with water, permitting the stream to stir up the contents, and allowed to stand for 10 minutes, when by means of a siphon extending to within 2.5 centimeters of the bottom of the receptacle, the water is siphoned off. More water is added, filling the receptacle, and at the end of 10 minutes siphoned off. Water is added again, and at the end of 5 minutes siphoned off. The process of 5 minutes' standing and siphoning is repeated until the water remains clear at the end of the 5 minutes' period. By this means the clay substance is separated from the grain, and may be collected in suitable containers and recovered by the addition of acid to

neutralize the sodium hydroxide.[8] The committee on Standard Tests, Trans. A.F.A. 37, (1929) page 554 recommends the following modification, "The minimum internal diameter of siphoning tube shall be 6 m.m.; the bottom of the tube shall be placed one inch from bottom of jar, and the lower end of the tube shall be curved upward being bent with a half inch radius to prevent suction of settled grains from bottom of jar. The tube is placed in jar just prior to siphoning. The outer leg of siphoning tube is to be 2 inches longer than inner leg."

[6]Since a 100-gram sample involves so many siphonings as to make the test prolonged, a 50 gram sample is more convenient to use.

[7]The disintegration of the sand in the revolving shaker requires an hour. At the suggestion of H. W. Dietert, the use of a motor driven milk-shake stirrer in the place of the rotary shaking apparatus is also approved, which accomplishes a satisfactory disintegration in five minutes, thereby saving 55 minutes of the time required to make the fineness test.

[8]For practically all known American molding sands this treatment is satisfactory. There are some foreign sands that are alkaline, and require an acid treatment, in which case tannic acid may be used.

The grain remaining in the bottle or jar is washed on to a filtering paper, in a 9 cm Buchner's funnel, is drained by means of suction, then wet with alcohol, and transferred, together with the filter-paper, to a large glass, and dried for one-half hour at 105° C., with a tolerance of 5°. The dried grain is weighed,[9] and the difference between its weight and that of the original 50 gram sample is ascertained to determine the clay substance.

The dried grain is then subjected to a screen analysis as for unbonded sands, except that the RO-tap machine is run for fifteen minutes instead of thirty minutes.

As both the Tyler Series and the Bureau of Standard Series are based upon an opening of .0029 inches corresponding to the 200 mesh screen, when made with wire of .0021 inch diameter, the Rittinger scale number as given above (Table III) can be used with either series without error.

Unfortunately this particular selection of screens originally recommended by the joint committee on Molding Sand Research[10] does not constitute a uniformly graduated series, as is evident from Table III. The rhythm of the Rittinger Series was sacrificed apparently for the sake of some slight economy in the purchase of screens. This lack of rhythm introduces some error in the interpretation of the screen analysis, and tends to conceal a fairly simple symmetrical distribution of grain sizes which definitely characterizes a large majority of all molding sands. For this reason in the tests conducted for the present investigation a more complete series of screens was used for making these fineness tests.

This lack of rhythm was recognized by the Sand Test Committee of the A.F.A.* and the U.S.B. of S. mesh screens, 50, 30, 16, and 8 were added since this work was completed.

[9]The filter-paper may be disposed of, after drying, by burning, as it lies on top of the sand sample.

[10]Transactions of the American Foundrymen's Assoc., Vol. 31, page 725.

*Report at Phila. Convention, May 1928.

Interpretation of Screen Analyses. The function of screen analysis is to determine the distribution of grain sizes in sand. There are two generally used methods of tabulating the data so obtained, the fractional method commonly used by American Foundrymen's Association, involving tabulation of the weight percentage trapped between each successive pair of screens; and the cumulative method, widely used in Europe and by the mining engineers the world over, involving tabulation of the cumulative percentages coarser than the successive mesh openings. The two methods, are equally legitimate when properly used; the choice between them being mainly the matter of personal opinion.

The data obtained in a screen analysis (Table IV) may be shown very satisfactorily in graphical plots, such as Figures 1, 2, and 3. Many graphical methods which do not take full recognition of the rhythm possessed by the Rittinger Series frequently yield grossly distorted pictures of the size distribution they are intended to portray.

Cumulative: The solid curves in Figures 1 and 2 are plotted from cumulative percentages. This method of plotting involves but one assumption which can affect its accuracy, that the distribution is continuous or that all intermediate grain sizes are present in the sample as well as those represented by the mesh of the screen on which the fractional part of the sample is retained. The cumulative plot establishes a definitely fixed relation between weight and dimension.

Rittinger No.	U. S. Bureau Standards Nominal Mesh	Fractional Weight Percent			Cumulative Weight Percent		
		Rittinger Ratio 1.41	A.F.A. Series	Rittinger Ratio 2	Rittinger Ratio 1.41	A. F. A. Series	Rittinger Ratio 2
7	6	0	0	0	0	0	0
6.5	8	0	0		0	0	
6	12	0	0	0	0	0	0
5.5	16	0	0		0	0	
5	20	0.03	0.03	0.03	0.03	0.03	0.03
4.5	30	0.08			0.11		
4	40	1.02	1.10	1.10	1.13	1.13	1.13
3.5	50	4.42			5.55		
3	70	17.81	22.23	22.23	23.36	23.36	23.36
2.5	100	25.45	25.45		48.81	48.81	
2.0	140	31.37	31.37	56.82	80.18	80.18	80.18
1.5	200	16.63	16.63		96.81	96.81	
1.0	270	2.30	2.30	18.93	99.11	99.11	99.11
.5	Pan	0.89	0.89	0.89	100.00	100.00	100.00
0							
Totals		100.00	100.00	100.00	100.00	100.00	100.00
Clay		0.20	0.20	0.20	0.20	0.20	0.20

Table IV. Fractional and Cumulative Screen Analyses of St. Joseph County, Michigan Core Sand No. 222 (Lab No. 2108).

Fractional: The fractional data are somewhat less acceptable as a basis for plotting curves, as the data plot merely indicates that a definitely determined weight of material is finer than one and coarser than the other of the two limiting mesh openings. This means that the distribution curve must lie between the determined limits, but its exact position is rather difficult to determine, as in Figure 3 the estimated distribution curve is indicated by the solid curve intermediate to the two limiting curves.

In Figure 2, the cumulative data have been used while in Figure 3, dependence has been placed entirely upon the fractional screen analysis.

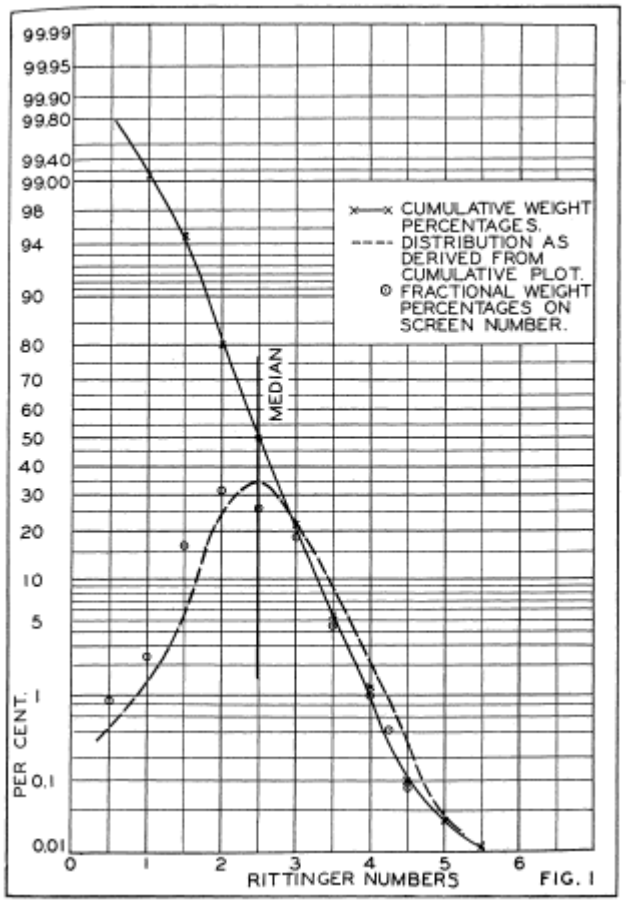

Figure 1. Screen analysis plotted on probability coordinates to show distribution of grain sizes according to Rittinger numbers.

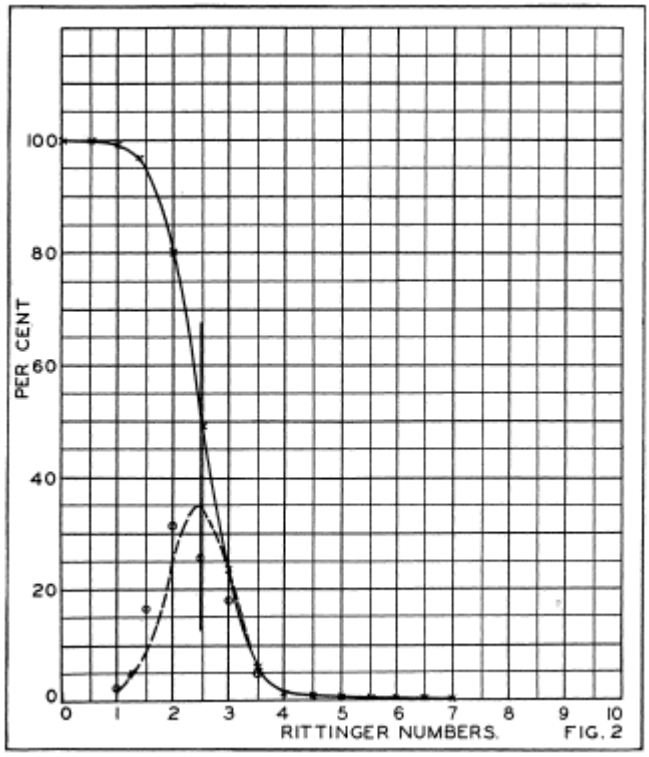

Figure 2. The same screen analysis as in Figure 1, plotted on rectangular coordinates.

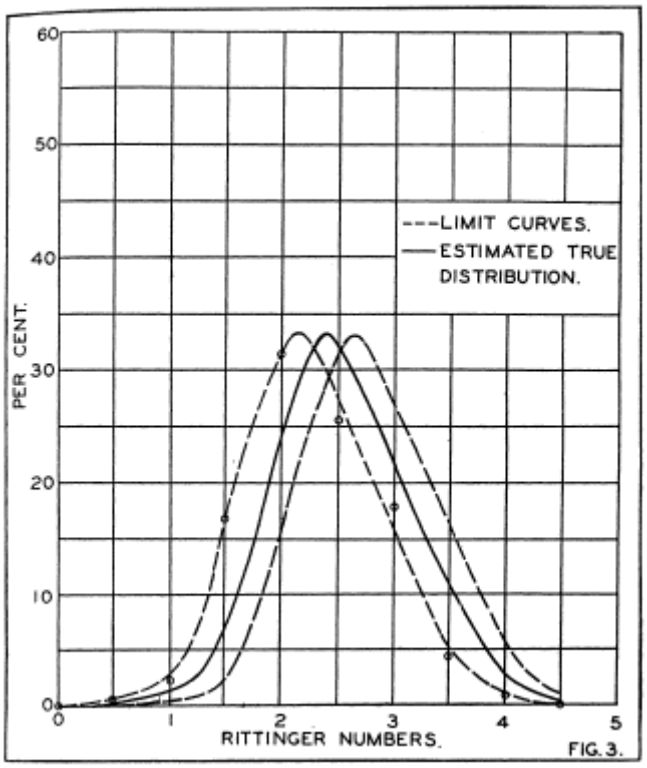

Figure 3. The same screen analysis as in Figures 1 and 2 plotted solely from fractional weight percentages on rectangular coordinates.

Probability Plot applied to Size Distribution: The coordinate system used in Figure 1 was proposed by Whipple[11] for plotting the probability function and has been used by Hansen[12] in plotting cumulative and fractional screen analysis data, as the distribution of grain sizes in sand should properly come within the scope of probability laws. Sands are deposited in Nature subject to classification by wind and water, conditions that are not sharply selective but still favor the deposition of a specific grain size in any particular deposit. The relative frequency of deposition of other grains should diminish fairly regularly as the deviation from the favored grain size increases, and the distribution of grain sizes should be more or less symmetrical to the selected or favored grain size. If this assumption is true, the Whipple probability coordinate combined with a correctly selected dimensional scale should give a straight line plot of a cumulative screen analysis. The slope of the line would indicate the exactness of the classification, or the uniformity of the grain size.

The advantages of such a plot are obvious, as the curve being nearly a straight line or a rather weakly flexed curve may be quite accurately drawn from relatively few determined datum points. This makes it unnecessary to have a complete set of screens in order to determine the size distribution and serves as a very satisfactory check on the accuracy of the screens used in the making of the tests.

The broken curve in Figure 1 is the distribution curve of fractional data, derived from the cumulative plot.

Although this coordinate system is peculiarly adapted for use in ploting screen analyses, several more readily available types of coordinate papers may be used to yield practically the same results. Figure 2 is an example of such a plot on rectangular cross-section paper.

[11]The Element of Chance in Sanitation, Journal of the Franklin Institute, Vol. 182, p. 205.

[12]Transactions of the American Foundrymen's Association, Vol. 34, 1926, p. 379.

FINENESS INDEX

For purposes of grading the fineness of sand, it is convenient if not actually necessary to adopt a single number as the criterion of the fineness or texture of the sand. The conventional numbers used in grading Albany Sand are based upon the texture of the sand as determined by the sense of touch of an experienced foreman.

A fairly rational fineness index may be derived from these cumulative curves as shown. Half of the sand by weight is certainly finer and half coarser than that screen sized corresponding to fifty percent on the cumulative curve. The fifty percent dividing line of a probability function would be its axis of symmetry or the median. This median may be adopted as the index of the fineness or texture of the sand.

Another fairly rational fineness index may be derived from the distribution curve plotted from the fractional data. One particular grain size contributes more than any other to the total weight of the sand, that grain size corresponding to the apex of the distribution curve may be called the predominant grain size. This is frequently the same as the median index, as they should be according to the assumption of continuous distribution of the particles throughout all sizes.

These fineness indexes calculated on the basis of the graphical method, are interesting and valuable, but are not well suited as a basis for the exact grading of deliberate mixtures of essentially dissimilar sands. Such mixtures are very seldom, perhaps never, found in nature but they are fairly common in the foundry and are quite frequently prepared by sand producers to blend over-bonded fine sand with coarser weakly bonded sand. For such mixtures the median index loses significance in that it is no longer an axis of symmetry. Likewise the predominant grain size loses significance in that there may be several equally predominant grain sizes. Under these conditions the interpretation of the graph depends entirely upon the personal opinion of the investigator, and different results may be expected by different investigators on the same material.

Similar graphical methods applied to very fine sands which have half or more of their weight beyond the capacity of our finer screens are also rather unsuitable as a basis for exact grading, since the personal equation enters to a large extent in extrapolating beyond the range of easily determined fineness.

For these reasons, it is considered preferable to use arithmetically calculated fineness indexes for exact standard grading of the fineness of sands. Even arithmetical fineness indexes of deliberate mixtures of dissimilar sands are somewhat arbitrary, but at least they possess the merits of being strictly definable so that all who apply the formulated method of calculation will at least reach the same conclusion.

A. F. A. Grain Fineness

The Grain Fineness Number of sand, adopted as tentative standard by the American Foundrymen's Association, is defined as "approximately the number of mesh per inch of that screen which would just pass the sample of sand if its grains were averaged in size. It is approximately proportional to the surface area per unit weight of a sand, exclusive of clay."

Method of Determination: "Make the standard A.F.A. fineness test by removing the clay and screening the grain. Multiplying the weights or percentages of sand on the various screens by the appropriate factors listed below. Add the products. Divide by the sum of the weights or percentages. The dividend is the A.F.A. *grain fineness number*."

Below are listed the multipliers for the corresponding U. S. B. of S mesh numbers:

	Multipliers
Percent on No. 6 mesh	3
Percent on No. 12 mesh	5
Percent on No. 20 mesh	10
Percent on No. 40 mesh	20
Percent on No. 70 mesh	40
Percent on No. 100 mesh	70
Percent on No. 140 mesh	100
Percent on No. 200 mesh	140
Percent on No. 270 mesh	200
Percent in pan	300

Grain Fineness Classification: A sand is in that grain class in which its grain fineness number falls according to the grain fineness zones.

Grain Class	
No. 1	200 to 300
No. 2	140 to but not including 200
No. 3	100 to but not including 140
No. 4	70 to but not including 100
No. 5	50 to but not including 70
No. 6	40 to but not including 50
No. 7	30 to but not including 40
No. 8	20 to but not including 30
No. 9	15 to but not including 20
No. 10	10 to but not including 15

In this method recommended as the *A.F.A. Fineness Number*, the screen sizes are indicated in terms of nominal mesh, rather than Rittinger number. The factor used to multiply the weight percent remaining on the screens represents the next largest size in the series adopted by the American Foundrymen's Association; so that this arithmetical computation is approximately equivalent to determining the area enclosed between the cumulative data curve and the vertical ordinate as in Figure 2, dividing by the height of the ordinate to determine the average screen size. If the multiplying factors were chosen to represent the next largest *intermediate screen* this approximation would be much closer.

The Rittinger Fineness Index

A more logical method of making this computation that would avoid these errors, involves the selection of uniform screen intervals, so that the ordinates to be averaged would be uniformly spaced. It also would seem preferable to substitute the Rittinger numbers as factors, rather than use the nominal mesh as a factor and then report the grain fineness n terms of arbitrary numbers based upon mesh size to determine the grain fineness classification. If these changes are made in the suggested method for determining the grain fineness number as has been done in Table V the results are practically identical with these obtained with the graphical methods described above.

Rittinger Screen Series—1.41 ratio.					Simplified Rittinger Screen series. 2.0 ratio.				
Limits	Average	Weight		Product	Limits	Av.	Wgt.		Product
7.5 — 7.0	7.25	0	=	0					
7.0 — 6.5	6.75	0	=	0	8 — 7	7.5	0	=	
6.5 — 6.0	6.25	0	=	0	7 — 6	6.5	0	=	
6.0 — 5.5	5.75	0	=	0					
5.5 — 5.0	5.25	0.03	=	.1575	6 — 5	5.5	0.03	=	.165
5.0 — 4.5	4.75	0.08	=	.380					
4.5 — 4.0	4.25	1.02	=	4.335	5 — 4	4.5	1.10	=	4.95
4.0 — 3.5	3.75	4.42	=	16.575					
3.5 — 3.0	3.25	17.81	=	57.8825	4 — 3	3.5	22.23	=	77.81
3.0 — 2.5	2.75	25.45	=	69.9875					
2.5 — 2.0	2.25	31.37	=	70.5825	3 — 2	2.5	56.82	=	142.05
2.0 — 1.5	1.75	16.63	=	29.1025					
1.5 — 1.0	1.25	2.30	=	2.875	2 — 1	1.5	18.93	=	28.39
1.0 — 0.0	.50	.89	=	.445					
		100.00		252.33	1 — 0	0.5	0.89	=	.445
							100.00		253.81

Rittinger Average Fineness Index $= \frac{252.3}{100.0} = 2.52$

Rittinger Average Fineness Index $= \frac{253.8}{100.0} = 2.54$

Table V. Calculation of Rittinger Average Fineness Index of St. Joseph County, Michigan Core sand. Sample No. 222 (Lab. Sample 2108).

Simple Series: An equivalent arithmetical method which is still simpler[13] may be carried out as follows: Add together the cumulative percentages as set down for the simplified screen series omitting to add the percentage set down against the number 0 screen, pan material. Divide this total by one hundred (100), and add five-tenths (0.5) to the quotient. For sand sample 222 (Table VI) the sum of the cumulative percentages is 203.81 and the index obtained by dividing this by 100 an adding five tenths is 2.54. Proceeding in this manner, each fraction added into the final total *n* times, where *n* is the Rittinger number of the limiting screens and therefore five tenths less than the proper value. As the five tenths error affects all fractions alike, the final quotient may be shifted back into proper position by adding five tenths.

This method is particularly simple where all screen analyses are tabulated cumulatively, and carries with it a triple check on accuracy.

[13]Hansen, Transactions of the American Foundrymen's Association, Vol. 34, page 383.

Extended Series: This additive correction of five tenths (0.5) may be applied only when using the screens in the Rittinger series numbered by whole numbers as 0, 1, 2, 3, 4, 5, 6. If a more complete series is used, (screens numbered 0, 0.5, 1, 1.5, 2, 2.5, etc.) the sum of the cumulative percentages should be divided by 200 and 0.75 should be added to the quotient.

It will be noted that all of the calculated indexes agree with one another and with the indexes determined by graphical methods in the case under consideration. This appears to be true for practically all natural sharp sands and for all natural sands, but as has been indicated will probably not be true for artificial mixtures where the sand has not been sorted by natural agents.

Cumulative Weight Percent		Cumulative Weight Percent	
1.41 Ratio:		2 Ratio:	
7.5 — 7	0	8 — 7	0
7 — 6.5	0		
6.5 — 6	0	7 — 6	0
6 — 5.5	0		
5.5 — 5	0.03	6 — 5	0.03
5 — 4.5	0.11		
4.5 — 4	1.13	5 — 4	1.13
4 — 3.5	5.55		
3.5 — 3	23.36	4 — 3	23.36
3 — 2.5	48.81		
2.5 — 2	80.18	3 — 2	80.18
2 — 1.5	96.81		
1.5 — 1	99.11	2 — 1	99.11
	355.09		203.81

$\frac{355.09}{200.0} = 1.7754$

$\frac{203.81}{100} = 2.04$

Rittinger Fineness Index $= 1.775 + .75 = 2.525$

Rittinger Fineness Index $= 2.04 + .50 = 2.54$

Table VI. Calculation of Rittinger Average Fineness Index of St. Joseph County, Michigan. Core Sand Sample 222. Equivalent Arithmetical Method.

All sands tested in this survey are reported in terms of the fineness index based upon the Rittinger numbers as tabulated above, as well as in terms of the A.F.A. grain fineness number, and grain fineness class as suggested by the American Foundrymen's Association.

There is a further advantage in using the Rittinger number in that these numbers agree closely with the grade numbers used for so many fears in classifying the Albany Sand, while the new grain fineness classification suggested by the American Foundrymen's Association is quite different from the conventional grade numbers used in the trade.

The Relation Between Rittinger Indexes and Albany Grade Numbers

Hansen[14] has compared the Albany grade numbers of over three hundred sands with the Rittinger Fineness Index as computed by the method described above.

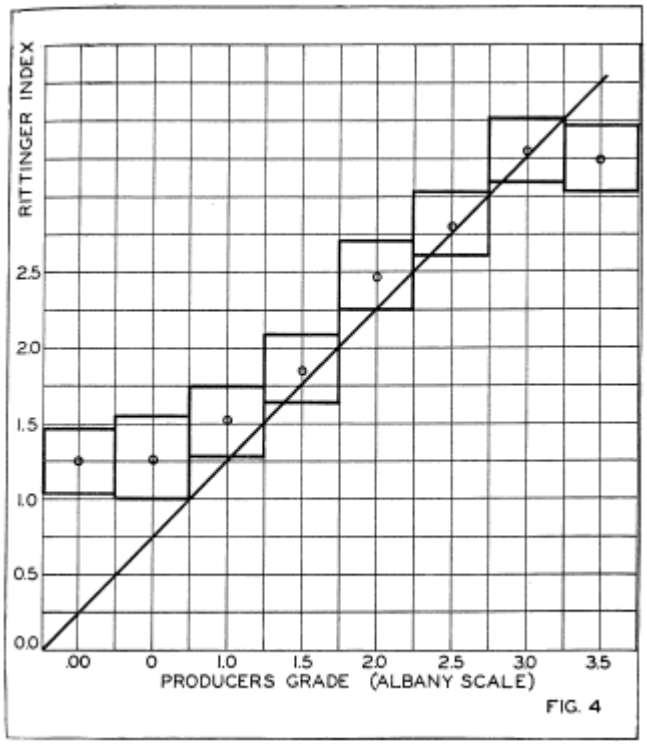

Figure 4. Rittinger Index as related to Albany Sand Scale.

Grouping the sands according to the producers grade numbers as taken from shipping memoranda the average fineness index for grade groups is found to be as indicated by the plot in Figure 4, in which Rittinger Index is plotted along the ordinate and the Producer's Grade Number, the Albany Scale, along the abscissa. The relation between Rittinger Fineness Index and Albany Grade Number seems to be approximately linear for grades 0 to 3 inclusive.

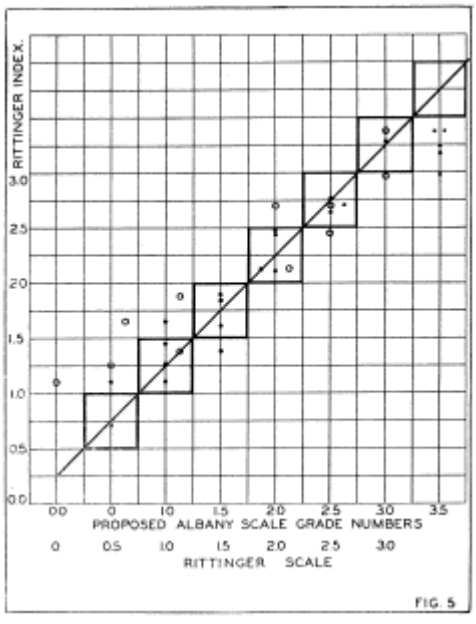

Figure 5. Rittinger Index as basis for Rittinger Scale or slightly raised Albany Scale.

The Rittinger Index for any given sand is a finite number while 'grade' inherently implies a limited range of fineness. Grades must necessarily overlap so long as sand continues to be graded commercially by purely touch sense. Sixty percent of the sands in each producer's grade group fall within the fineness limit indicated by the rectangles in Figure 4.

It is to be noted that grade 00 and 3.5 are essentially identical with grades 0 and 3 respectively both in regard to average fineness and to range of fineness. As a matter of fact, there are no commercially available sands in the Albany District finer than No. 0 or coarser than No. 3, as these grades are defined in Figure 4. Grade 00 and 3.5, or occasionally 4 and 5 are thus of value as selling points rather than as descriptions of the fineness of Albany Sand.

Because of the essentially linear character of the relation between Albany grades and the Average Rittinger Index, Hansen proposes that molding sands and core sands be classified into "Rittinger Fineness Grades" according to Rittinger Fineness Indexes, as shown in Figure 5. The same relation can be extended indefinitely to cover the coarser sands used anywhere in the foundry. This proposed grade classification is essentially that of classifying the fineness of a sand according to the nearest half unit of the Rittinger Fineness index having a numerical value below that of the Rittinger Index. Such proposed grades differ but slightly from the present Albany Sand grades and offer the advantage of close agreement with the size grade now in common use throughout foundry industry.

[14]Transactions of the American Foundrymen's Association, Vol. 34, page 386.

SIZE DISTRIBUTION

Sand of uniform grain size has quite different characteristics from a sand of the same average grain fineness but of a wide range of grain size. The latter packs more densely with the small grains tending to fill the spaces between the larger ones, giving a sand of lower permeability and generally higher green bond strength. At present there is no standard method for expressing grain distribution numerically.

Methods: A uniformity coefficient used in connection with classifying filtering sands is determined by dividing the dimension of the screen opening which will pass sixty percent of the samples by the dimension of the screen opening that will pass ten percent of the sample.

The A.F.A. Grain Size Distribution. Another method suggested by A. A. Grubb, chairman of the Sub-Committee of Grading,[15] is to divide the average mesh as determined by Ries and Rosen,[16] by the A.F.A. grain fineness number. Ries' method divides the amount of sand retained on each screen by the same number as used for a multiplier in A.F.A. grain fineness number, and divides the total sum of the quotients so obtained

[15]Transactions of the American Foundrymen's Association of America, Vol. 35, 1927.

[16]Michigan Geological Survey, Annual Report, 1907, page 50.

by the amount of sand used in making the test, the final quotient giving the average size of the sand. The reciprocal of this figure representing the average size of the sand, is a figure representing the average mesh of the sand particles. As the multipliers used in A.F.A. grain fineness number, or the divisors used in determining Ries' average particle size, increase with increasing fineness of the particles it is clear that the A.F.A. grain fineness number weighs the fine material while Ries' method weighs the coarse material. If the sand is all of uniform size the A.F.A. grain fineness number is exactly equal to Ries' average mesh, and the grain distribution as determined by dividing the average mesh by the grain fineness number is unity.

This method of indicating the grain distribution takes into consideration the entire screen analysis and is a definite measure of grain distribution based upon unity for a single grain size and correspondingly decreasing numbers for sand possessing a wide range of grain sizes. Table VII shows the method of computing this factor for sample 222.

Calculation of A. F. A. Fineness Index

Screen Interval	Fact.	Weight	Product
—6 + 12	5 x	0. =	
—12 + 20	10 x	0.03 =	.30
—20 + 40	20 x	1.10 =	22.00
—40 + 70	40 x	22.23 =	889.2
—70 + 100	70 x	25.45 =	1781.5
—100 + 140	100 x	31.37 =	3137.0
—140 + 200	140 x	16.63 =	2328.2
—200 + 270	200 x	2.30 =	460.
—270 + Pan	300 x	0.89 =	267.
		100.00	8571.2

$$\text{A. F. A. Fineness Index} = \frac{8571.}{100} = 86.$$

Calculation of Ries Fineness Index

Screen Interval	Fact.	Weight	Product
—6 + 12	1/5 x	0. =	
—12 + 20	1/10 x	0.03 =	.003
—20 + 40	1/20 x	1.10 =	.055
—40 + 70	1/40 x	22.23 =	.556
—70 + 100	1/70 x	25.45 =	.364
—100 + 140	1/100 x	31.37 =	.314
—140 + 200	1/140 x	16.63 =	.121
—200 + 270	1/200 x	2.30 =	.011
—270 + Pan	1/300 x	.89 =	.003
		100.00	1.427

$$\text{Ries Av. Size} = \frac{1.427}{100} = .01427 \text{ inches}$$

$$\text{Ries Av. Mesh} = \frac{1}{.01427} = 70$$

$$\text{Grain Size Distribution} = \frac{\text{Ries Average Mesh}}{\text{A. F. A. Fineness Index}} = \frac{70}{86} = .815$$

Table VII. Calculation of A. F. A. Grain Size Distribution of St. Joseph County, Michigan. Core Sand, Sample No. 222.

Following are four screen analyses, all of the same A.F.A. grain fineness but varying in distribution:

	(1)	(2)	(3)	(4)
On 6				
12				
20				6
40			6	12
70		5	10	15
100	90	80	60	30
140		5	9.5	15
200			4.5	10
270				2
Pan				
Clay Substance	10	10	10	10
A. F. A. Grain Fineness	70	70	70	70
Av. Mesh (Ries)	70	68.4	58.8	40.1
Grain Distribution	1.00	.98	.84	.57

Rittinger Grain Size Distribution. Much, the same results are obtained by applying a similar method to the Rittinger Fineness Index. The "average Rittinger size" may be computed by dividing by the same average Rittinger number of the screen interval as used as multiplier in computing Rittinger Index and dividing the sum of these quotients by the total weight of sand. The reciprocal of the last quotient is then divided by the Rittinger Fineness Index (Table V) to yield the Rittinger Grain Size Distribution as described in Table VIII.

Rittinger Screen Series—1.41 Ratio

7.5 — 7.	1/7.25	.1379	x	.0	=	
7 — 6.5	1/6.75	.1481	x	.0	=	
6.5 — 6	1/6.25	.1600	x	.0	=	
6 — 5.5	1/5.75	.1739	x	.0	=	
5.5 — 5	1/5.25	.1905	x	0.03	=	.005
5. — 4.5	1/4.74	.2105	x	0.08	=	.017
4.5 — 4	1/4.25	.2353	x	1.02	=	.240
4. — 3.5	1/3.75	.2667	x	4.42	=	1.180
3.5 — 3	1/3.25	.3077	x	17.81	=	5.475
3 — 2.5	1/2.75	.3636	x	25.45	=	9.23
2.5 — 2	1/2.25	.4444	x	31.37	=	13.930
2 — 1.5	1/1.70	.5714	x	16.63	=	9.49
1.5 — 1	1/1.25	.8000	x	2.30	=	1.84
1 — 0.0	1/0.5	2.0000	x	0.89	=	1.78
				100.00		43.187

$$\frac{43.187}{100} = .43187$$

$$\text{Average Rittinger Size} = \frac{1}{.43187} = 2.313$$

$$\text{Rittinger Grain Size Distribution} = \frac{\text{Average Rittinger Size}}{\text{Rittinger Fineness Index*}} = \frac{2.313}{2.52} = .918$$

*Tables V and VI.

Rittinger Screen Series—2 ratio.

8 — 7	1/7.5	.1333	x	0		
7 — 6	1/6.5	.1538	x	0		
6 — 5	1/5.5	.1818	x	0.03	=	.005
5 — 4	1/4.5	.2222	x	1.10	=	.245
4 — 3	1/3.5	.2857	x	22.25	=	6.355
3 — 2	1/2.5	.4000	x	56.82	=	22.528
2 — 1	1/1.5	.6667	x	18.93	=	12.630
1 — 0	1/0.5	2.000	x	0.89	=	1.780
				100.00		43.543

$$\frac{43.543}{100} = .43543$$

$$\text{Average Rittinger Size} = \frac{1}{.43543} = 2.292$$

$$\text{Rittinger Grain Size Distribution} = \frac{2.292}{2.54} = .904$$

Table VIII. Calculation of Rittinger Grain Size Distribution of St. Joseph County, Michigan. Core Sand Sample 222.

SHAPE OF SAND GRAINS

In addition to the size, and size distribution, the shape of the grain is an important factor determining the physical properties of the sand.

The compressive strength of a sand composed of angular or irregular shaped grains is considerably higher than that of a sand composed off round grains. The ability of the irregular or angular grain to interlock, would have a similar effect on the transverse and tensile strength of sands composed of angular grains.

The different shapes of the grain also have an effect on the permeability. In general, however, the importance of the shape of the grain lies entirely in the effect of this characteristic on the other physical properties of the sand, rather than upon the direct effect of the grain shape itself.

The only satisfactory way to determine the predominate shape of the grains contained in a sand is by a microscopic analysis. Because grain shape does not help in any direct evaluation of the sand, this test was omitted in the present survey.

COMPOSITION OF SAND GRAINS

The mineralogical composition of the grains is an important factor in many ways. In making steel casting where the temperature of the metal as it is poured into the sand is higher than in the other branches of the industry, it is important that the sand be composed of mineral which can resist the high temperatures without

breaking down or without fusing with the iron. The same properties are desirable in coarse molding sands which are used for making heavy iron castings, as in the heavy castings the large amount of heat contained in the thick parts of the castings, cause the sand to be heated to a high temperature. In work of this kind, it has been found[17] that when molding sand is used in which the sand grains are not silica, that the sand grains have a tendency to break up into smaller grains of angular shape. One sand is reported to have broken up so rapidly that at the end of six months the sand was about one-half as coarse as at the beginning of the period. This difficulty was largely overcome by mixing a highly bonded molding sand with silica sand grains as a base. For large work there is a definite field for silica mixed with highly bonded molding sands or other bonding material.

[17]Dietert, Transactions of the American Foundrymen's Association, Vol. 33, page 857.

ADSORPTION

It was early recognized[18] that the clay substance as determined in the rational analysis based upon an estimation of the chemical compounds present could not be used as a proper indication of the amount of clay or-bonding sand.

In an effort to find a satisfactory method of determining the amount of bonding material in the sand, the dye-adsorption test was developed on the assumption that the amount of colloid matter roughly represented the amount of bonding material present in the sand and that the amount of colloid present in the sand was represented by the amount of dye which was adsorbed by the sand from a solution of constant value and composition.

[18]Moldenke, Transactions of the American Foundrymen's Association, Vol. 21, 1913.

THE DYE ADSORPTION TEST

The Dye Adsorption Test is conveniently made in a short time and has received considerable attention for this reason, although it was never proposed as a precise test to indicate the amount of bonding material present. A satisfactory method for making the dye adsorption test is given by Harrington, MacCombe, and Hosmer.[19]

Twenty-five grams of molding sand dried at 105°C. for one hour are weighed into a 500 c.c. wide-mouth bottle fitted with a glass stopper and containing 300 c.c. of distilled water plus 5 c.c. of 10 percent ammonium hydrate. The bottle is stoppered, sealed with paraffin wax and placed in a suitable rotating machine for one-half hour. At the end of this period 90 c.c. of distilled water, and 5 c.c. of 10 percent acetic acid are added. Crystal violet dye is then added in sufficient weight to allow for the adsorption by the colloidal matter and leave a slight excess. For molding sands of weak bond about .125 grams of dye are required; the stronger sands require addition of .150 to .300 or more grams of dye.

After adding the crystal violet dye the bottle is sealed again and rotated for another half-hour period. If all the dye is taken up by the colloidal matter an additional weight of dye should be added, as it is necessary that an excess of dye be present over that required to satisfy the adsorption capacity of the colloids.

The amount of dye adsorbed by the sand is determined from the quantity unadsorbed or held in solution. If the test is allowed to stand over night, suspended material settles out, leaving a clear solution of the dye stuff, and the dye unadsorbed can be determined by color comparison. The result is expressed as milligrams of dye adsorbed per 100 grams of sand.

[19]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 47.

Electrotypes

Ammonium acetate aids in settling the fine particles which otherwise would remain in suspension. It has no serious effect on crystal violet. The addition of ammonium hydrate acts as a partial deflocculator and thereby breaks up the agglomerations of clay or other bonding substances!

Dye

Only the highest grade of pure dye crystal violet should be used. Impure commercial dye gives low figures and is unstable. Standard dye solution should be kept in the dark, and a fresh quantity should be prepared frequently.

Dye Concentration

The final concentration of crystal violet should be not less than 0.024 grams, or more than 0.060 grams, in 400 c.c. of solution. A greater excess of dye gives high reading. After making a few tests it is a simple matter to judge the density of the clear dye solution, and it is essential that the proper concentration is obtained before the test settles overnight.

Used Sands

The dye adsorption test cannot be relied upon for all grades of used sands. Impurities present in some heap sands, such as sea-coal, iron scale, organic binders, etc. seriously affect the adsorption results.

It should be well to point out that the term, clay substance or clay content, to a foundryman really indicates bonding material, and that the use of dye-adsorption as an indication of clay content or bonding material assumes that the one outstanding property of bonding material is active surface capable of adsorbing soluble salts. Condit[20] calls attention to the fact that the extremely fine particles in molding sands of a size of .0002 inch in diameter and smaller ordinarily spoken of as "clay" contain mineral matter not greatly different from that of the coarser material. He notes that limonite and hydrous aluminum silicates are in some cases the constituent of this fine material, but that quartz, tourmaline and many other minerals are also present.

[20]Transactions of the American Foundrymen's Association, Vol. 21, page 28.

Interpretation of Dye-Adsorption Test

Although the results of the dye-adsorption test cannot be readily interpreted, in terms of bonding material, clay content, or strength, it does bear some relation to the physical condition of the bonding material in the sand.

There is a theory that the plasticity of clays is dependent upon adsorbed salts or upon the ability of the clay to adsorb soluble salts. In many ways the bond or strength in molding sand is known to vary with the plasticity or fatness of the clay contained therein, and it seems reasonable that adsorption measures in some way a quality of the clay present in the sand, somewhat similar to the plasticity of the clay.

This interpretation is borne out by the results of tests made on the same molding sand which has been heated to different temperatures. In all cases the dye adsorption test shows less dye adsorbed as the sand is heated to higher temperatures corresponding to the decrease in the plasticity of clays heated to approximately the same temperatures.

However, it is not safe to assume that the dye-adsorption test measures the quality of the bond in the sand or the degree of bonding possessed by the sand, as these properties depend upon other factors than simply the immediate colloidal condition of the sand. For these reasons the dye-adsorption of a sand is considered as a separate physical property of the sand, and not as an indication of the clay content of the sand or of its bond. Because of the questionable interpretation of the dye adsorption test, this test was not made on all of the Michigan sands collected in this survey.

PERMEABILITY

Permeability is that quality of sand which allows the passage of gas through the sand. It is a requisite and an important property of molding sand for the reason that gases from the molten metals and the steam developed when the hot metal comes in contact with the moist sand of the mold must have free escape through the sand in order to prevent the formation of blow-holes in the casting.

It is perhaps well to differentiate between porosity and permeability. Theoretically it can be shown that the free volume between the grains of sand is independent of the *size of the sand particles*, provided all the particles are of the same size and are spherical. The smaller particles, however, offer more friction to flow of air through the sand, and accordingly we find that the fine grain sands have a lower permeability.

For much the same reason it is evident that the *distribution of the grain size* will have a very important influence on the permeability of the sand.

SHAPE OF THE GRAIN

Shape of the grain also, has an important influence on the permeability of the sand. Although angular grains when packed together have a larger free space than rounded grains, the permeability of the sand composed of angular particles is lower than that of a sand composed of rounded particles of the same grain size, because the angular particles offer more friction to the flow of air through the sand.

DEFINITION

Permeability must be measured in terms of the amount of air passing through a given area of sand of a given thickness when the air is force through the sand under a specified pressure. The permeability test adopted as standard by the American Foundrymen's Association[21] defines the permeability of a sand as the number of cubic centimeter of air that can be forced in one minute through a cylinder of sand 2 inches in height and having a diameter of one inch under a pressure differential of one gram per square centimeter.

[21]Bulletin, Aug. 1, 1924.

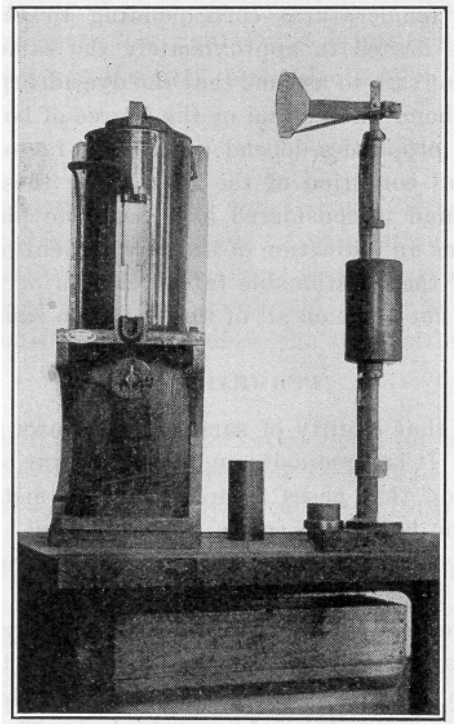

Figure 6. Apparatus for permeability tests.

METHOD OF TESTS

Complete description of the American Foundrymen's Association Standard Permeability Test may be found in the Transactions of the Association, Vol. 31, page 708 (1924).

Essentially the equipment consists of a gasometer provided with a vertical air outlet tube passing through the bottom. The outlet tube is equipped with a three-way valve directly below the air gasometer which controls the

flow of air through the sand specimen. The air pressure on the sand is indicated by the water manometer on the front of the apparatus as shown to the left of Figure 6.

In operation the valve is turned to 'vent' and the bell of the gasometer raised, filling it with air over the water sea when the valve is closed. The rammed sample of sand in a brass cylinder is connected below the valve by forcing the cylinder over a rubber stopper on the lower end of the air outlet tube. Sufficient weight is placed on the air bell to develop 10 cm. of pressure on the manometer. The tube is opened and the time recorded for 2000 c.c. air to flow through the sand sample under a pressure of 10 cm. of water, as determined by a stop watch.

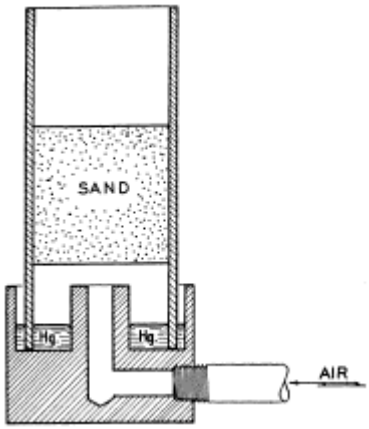

Figure 7. Modified method of holding sand for permeability tests.

The sand container shown in center of Figure 6 is a brass cylinder 5 inches high and 2 inches inside diameter.

The Sand Rammer

The Sand Rammer shown at right in Figure 6 consists of a steel rod, supported by two guides. A steel disc is attached to the lower end of the rod, and has a sliding fit in the sand container. A cast iron rammer head, weighing 14 pounds slides on the rod, its movement of 2 inches being regulated by two stops. A pedestal is provided on which the sand container E rests while sand is being placed in it, and while the ramming operation is performed.

The rammer usually carries on top of the upper steel support a scale indicating the limit of the height of the specimen after ramming. In the Chemical Engineering Laboratories of the University of Michigan this tolerance gauge has been replaced by an accurate height indicator as shown. This indicator consists of a brass frame on which is pivoted a light beam carrying a knife edge one inch from the pivoted end. The scale at the left end of the indicator beam is calibrated from 1.75 inches to 2.2 inches by hundredths of inches, by placing Johnson gauge blocks on top of the pedestal on which the rammer is rested. The beam is then swung into position with its knife edge on the upper end of the rammer to indicate accurately the actual height of the sand sample after ramming. The actual height of the sample so determined is then used in the formula to determine the permeability of the sample instead of assuming a constant height of sand within the tolerance limits as specified by the American Foundrymen's Association.

Another modification increasing the speed and accuracy is indicated in Figure 7. The permeability sample is rammed in a cast iron cylinder of the same internal dimensions instead of the brass tube as described above. This cylinder containing the rammed sand is then placed in the cup carrying a mercury seal as shown, instead of forcing it over the rubber stopper at the bottom of the gasometer. This modification eliminates possible air leak around the rubber stopper caused by hasty handling of the tube, sand on the rubber stopper or upper part of the tube. In testing dry sand for base permeability there is no tendency to loosen the sand from the cylinder as is frequently done in forcing the cylinder over the rubber stopper. A special cap having a 20 mesh brass screen bottom should be placed over the end or in the sand container when testing dry sand.

Procedure

In testing sand for permeability it is absolutely necessary that the sand be properly sampled and uniformly tempered. For plant check or control tests upon facing or heap sands in daily use, one may test the sand as tempered for molding.

Since it is the object to determine the maximum permeability under suitable foundry working conditions, in the examination of new sands experiments should invariably be made with several water contents in order to ascertain that amount which develops the maximum degree of permeability (optimum water content). It is advisable in most cases to try percentages of water beginning with 4 percent and increasing by stages of 2 percent, up to and including 8 percent. A deviation not exceeding .2 percent (5.8 per cent or 6.2 percent in the case of an attempt I get 6 percent) may be neglected for the determination of the permeability at the nearest fixed percentage. The exact percentage of moisture, even if within 0.2 percent of the desired fixed percent, should be reported.

Supplementary tests with lower percentages of water than 4 percent and higher percentages than 8 percent should be made if and when the facts ascertained justify such tests.

PREPARATION OF SAMPLE

Preparation of Sample. In the *examination of new sands*, 1000 grams of sand, is spread over a large area in a thin layer in order to expel the moisture rapidly and dried for one hour at a temperature of not below 105 degrees C. nor above 110 degrees C.

After the sand has cooled the desired quantity of water is measured including extra water (usually from one-fourth to one percent of the moist sand) to allow for evaporation.

For the *tempering operation*, spread the sand on a smooth flat dry surface in a layer about 1 inch thick, sprinkle a small quantity of the required water evenly over the sand, and work the latter gradually. Again spread it into a thin layer and repeat the above operations, adding more water, until all of the water has been thoroughly distributed through the sand. There should be no dry lumps or other particles of uneven tempering.

The sand is then allowed to stand in a humidor or air tight container for 24 hours in order that the maximum temper may be developed. The entire sample of sand from the humidor is twice passed through a coarse riddle and returned as quickly as possible to the humidor. Samples to be tested for permeability moisture content, and for cohesiveness or bond strength are taken as desired.

MOISTURE CONTENT

Moisture Content. Dry 100 grams of tempered sand for one hour between 105 degrees and 110 degrees centigrade. When dry reweigh. The loss of weight in grams is the moisture content expressed as percentage.

RAMMING OF SPECIMEN

Ramming of specimen. A sufficient quantity (from 150 to 200 grams) of tempered sand to make a column 2 inches high is carefully placed in the sand container and gently leveled off. With pedestal and container in position beneath rammer, gently lower rammer-rod with head into container until supported by the sand. Raise rammer-head to the upper stop, and let fall. Repeat twice making a total of 3 rams. Note whether the upper end of the rod is within the tolerance marks, if not, discard the sample and put in another lot of the required height. This is usually accomplished on the second trial.

Note exact height of sand and lift rammer-rod until disc at lower end of rod is free from sand container, and take container off pedestal.

Calculation of Permeability

The degree of permeability as determined by this test equals the number of cubic centimeters of air forced through the sand specimen, multiplied by the height of the sand specimens in centimeters; and divided by the pressure in grams, the area of the sand specimen in square centimeters and the time in minutes.

$$\text{Permeability} = \frac{\text{cm}^3 \text{ of air} \times \text{cm height of specimen}}{\text{grams pressure} \times \text{cm}^2 \text{ area of specimen} \times \text{min.}}$$

Substituting the fixed quantities in the above equation the permeability equals

$$\frac{2000 \times \text{height of specimen in cm.}}{20.268 \times \text{grams pressure} \times \text{minutes}}$$

BASE PERMEABILITY

Base permeability is the permeability of the base sand grains without the inclusion of any bonding material. Therefore, base permeability is affected only by the factors, grain size, grain shape, and size distribution. Its importance lies in the fact that as the clay and bonding material are burned out of the molding sand in actual use, the permeability of the sand tends to approach the base permeability. If new sand is added to burned out sand the base permeability of the new sand is particularly important as indicating whether the new sand will tend to decrease the permeability of the sand heap or not.

Base Permeability Test

Approximately 300 grams of sand are washed free from clay in the same manner as for the fineness test. The dry sand is then tested for permeability.

A screen 200 mesh for fine samples and 100 mesh for coarser samples, is used in the lower end of the permeability cylinder to aid in supporting the dry unbonded sand during the ramming and testing. Sorting of grain sizes in dry sand is a more serious difficulty than in the natural bonded sands and may produce a silt layer in the sand specimen which is more impermeable than the sample as a whole. For this reason, check determinations are particularly important in determining the base permeability. In general, at least five runs should be made on the same sample to obtain a fair average.

Effect of Grain Size on Base Permeability

M S. Littlefield[22] has made an interesting investigation concerning the effect of grain size distribution upon the base permeability (Table IX).

On 40 %	On 70 %	On 100 %	On 200 %	Pan —270 %	Base Permeability
.....	100.0	.....	.....	.....	236.7
.....	.....	100.0	.....	.....	56.8
.....	.....	.....	100.0	.....	25.8
.....	50.0	50.0	.....	.....	82.7
.....	.....	50.0	50.0	.....	29.4
.....	33.0	33.0	33.0	.....	32.8
.....	25.0	25.0	25.0	25.0	6.7
20.0	20.0	20.0	20.0	20.0	8.9
14.3	42.8	14.3	14.3	14.3	19.2

Table IX. Base Permeability of Different Sand Mixtures.

It is clear that once the base permeability is reduced by the presence of fine material, it cannot be materially increased except by an addition of a large proportion of coarse sand.

Table X gives data which show the reduction in permeability of a 70 mesh sand by the addition of silt.

Sand On 70 Mesh %	Silt —270 Mesh %	Base Permeability %
100.0	.....	236.7
96.8	3.2	165.7
93.7	6.3	96.0
90.9	9.1	79.1
88.3	11.7	38.1
85.6	14.4	27.8
83.4	16.6	21.4
81.1	18.9	20.1

Table X. The Effect of Silt on Base Permeability.

The amount of reduction is progressively less with the increase in proportion of silt, until finally greater admixtures of silt fail to reduce the permeability

appreciably. Further addition of silt beyond the limit shown in the above table resulted in the formation of layers of silt within the sand. Just as if the pore space of the sand were completely saturated with the silt.

[22]Bulletin 50, Natural Bonded Molding Sand Resource of Illinois, Illinois State Geological Survey, page 44.

Effect of Grain Shape on Base Permeability

Changes in grain shape are relatively less important than changes grain size. Ottawa silica sand, made up of well rounded grains, is compared with the sand from Albany molding sand, generally considered to be angular, in Table XI.

Size Grade A. F. A.	Base Permeability		
	Ottawa Silica	Albany	Mixture of Grains from 20 Illinois Sands
70	228.7	....	236.7
100	84.3	60.4	56.8
140	53.1	50.1	44.2
200	32.7	14.9	23.8

Table XI. Effect of Grain Size and Grain Shape on Base Permeability.

The round grains (Ottawa) give the higher base permeability, even in the above table, where the differences in the grain shape are probably not as great as might be expected in comparing beach sands or san composed of well rounded grains, with extremely sharp sand as that produced by crushing quartzite or similar material.

BOND STRENGTH

Perhaps the most important single property of a molding sand is that it possesses sufficient strength so that when moist the sand will retain the shape of the pattern, and maintain that shape against the washing effect of the molten metal in order to produce an accurate casting. Strength, moist and dry, with permeability, are the major properties of molding sand.

In making large castings, coarse sands are used and must possess a higher degree of strength than fine sands used for smaller castings because the washing action of the molten metal is greater and the casting is heavier. Sands used for small or light castings do not require such high bond strength, but the molding of intricate patterns calls for a fairly constant bond strength over a wide range of moisture content.

INDIRECT METHODS OF DETERMINING SAND STRENGTH

Sense of Touch

For many generations the strength of a molding sand has been estimated from the *sense of touch*, or feel, as exercised by the foundry foreman or sand producer. When foundries were small and the production not large, perhaps this method was as satisfactory as any that could be proposed, but in the present age of large scale production and scientific control, it is necessary that this method, entirely dependent upon the skill of an individual, be replaced by a more scientific method capable of wide application by different individuals.

Clay Content

Because the clay content of the sand is a very important factor influencing the feel of the sand, it was early recognized that the *clay content*, or clay substance in the sand, bore an important relation to the strength of the sand. Some methods proposed for determining the bond strength of sand over-emphasized the importance of the clay content, and attempted to measure the clay content instead of the bond strength directly.

The Dye-adsorption Test and Vibratory Test for Clay Content

The dye-adsorption test as a measure of bond strength, is a similar indirect method and attempts to measure the colloid matter in the sand. Although the clay content and colloidal conditions are important factors in determining the bond strength of the sand, other factors enter in and no indirect test can ever hope to measure the actual bond strength of a sand. For this reason neither the dye-adsorption test nor the *vibratory test* in which the amount of clay substance present in the sand is separated from the sand by hydraulic classification and estimated by volume, have been used in this report as a criterion of bond strength.

DIRECT METHODS OF DETERMINING BOND STRENGTH

T. C. Adams[23] has outlined most of the important strength tests now being used on molding sands. The fundamental stresses to which sand may be subjected are tension, compression, and shear. Other stresses such as cross-breaking, bending, or transverse stressing are recognized, but simply as combinations of the above three fundamental stresses.

A compressive test consists in compressing the specimen until it collapses.

[23]Transactions of the American Foundrymen's Association, Vol. 34, page 404, 1926.

A Shear Test

A shear test is not generally used and has only recently been introduced in actual testing but it is meeting with general approval.

The Transverse Test

The transverse test involving a combination of tension and compression and possibly shear made by bending a bar of sand until it separates into two pieces has been widely used. Because the sand is much weaker in tension than in compression, the transverse test produces failure of the test bar due to tensile stresses. But because the neutral axis of the transverse test bar is not always in the same position, depending upon the ratio between the comprehensive and tensile strength, the bar fails in tension over a varying cross section. For

this reason, and because the transverse test causes failure partly by shear, there is no direct relationship between failure in a tensile and in a transverse test. In actual use in the foundry, sands may be subjected to compression, tension, shear, or to a complex combination of these stresses, and no doubt the transverse test offers important and valuable information concerning the functioning of the sand in actual molds.

For scientific research work, it is necessary to adopt a more precise and accurate method for testing the bond of the molding sand than would ordinarily be necessary in plant or routine control work in a foundry. Many tests eminently suited for foundry work would prove unsuited for the purposes of research embodied in this bulletin.

The American Foundrymen's Association Cohesiveness Test

The cohesiveness test adopted as standard by the American Foundrymen's Association and used in testing the Michigan sand samples sent to Cornell or Washington consists essentially in pushing a bar of compacted sand over the edge of a table and weighing the pieces which break off as the sand is forced forward at a uniform rate. 1000 grams of dry sand properly tempered are used for test and the cohesiveness is expressed as a percentage obtained by dividing the average weight of pieces by 500. Inspection of this test clearly indicates that the sand fails much as in a transverse test, and is subject to all of the errors of such a test. Detailed description of this test may be found elsewhere[24] and is not given here because it promises to be discarded in favor of compression or other tests.

[24]Transactions of the American Foundrymen's Association, Vol. 31, page 687, 1924.

Compression Tests

Numerous other tests involving failure of the sample in simple compression or simple tension have been proposed and since this work was completed have superseded the cohesiveness test. Hansen[25] describes a compression test machine involving the use of the permeability sample as prepared in the manner described. The sample is loaded by means of lead shot falling into a pail on one end of a beam which is supported at a fulcrum and on the compression test sample. The strength of the sample is reported in terms of pounds per square inch maximum stress.

The dimensions of the sand cylinder used in the permeability test are not well adapted to a compression test as a cylinder of the same diameter and height is apt to break in the faces. With the ideal or homogenous short cylinder breaking under compression, the angle of fracture would be 45° with the round face of the cylinder, assuming that all the samples of sand have the same unit tensile and compressive strength. Since this is not strictly true, the angle varies for different material. As shown by Boyd[26] "failure takes place along a plane which makes an angle of 45° plus one-half the angle of friction with the plane normal to the compressive force." With samples breaking in the face, it is evident that the compressive load is not supported by the entire cross-sectional area, but only by a part thereof.

Another compression test suggested by H. W. Dietert[27] loads the sample by hydraulic pressure using the tester shown in Figure 8 and in detail in Figure 9. The rammer constructed as shown in Figure 10 is generally similar to that used for ramming the permeability sample except for dimensions.

The mold and bottom rammer (Figure 11) are built to a loose fit so that the sand is supported entirely on the bottom rammer allowing the lower end of sand sample to be rammed with the same force as the upper end of the sample.

In operation, the sand tempered as for the permeability test, is placed in the mold supported by the stop pin over the bottom rammer. The mold assembly is then placed under the rammer which is allowed to rest on the sand. The stop pin is removed and the sand rammed by one fall of the seven pound weight through 2.56 inches.

The sand cylinder is then forced out of the mold by the bottom rammer, blown free of loose sand, arid placed in the compression tester. The hand wheel of the oil plunger is then turned at the rate of 120 r.p.m. until the specimen breaks.

Turning this hand wheel drives the plunger into the cylinder compressing the oil into the system. The oil pressure supported by the sand specimen is registered by the pressure gauge. The maximum reading of the gauge, or the crushing strength of the sand, is recorded as the "strength." A single reading is sufficient to determine the strength of a heap sand in plant control work provided the operator is experienced. However, for a new sand it is desirable to make at least three readings and record the average as the strength value.

The area of the piston head is one quarter of a square inch. Thus every pound per square inch in the oil system exerts on the piston head only one quarter of a pound. This pressure is supported by the sand specimen whose area is one square inch, so that every pound per square inch in the oil system exerts one quarter of a pound per square inch on the specimen. Should a standard gauge be used, its readings must be divided by four to give pounds per square inch strength of the sand.

The dimensions of the cylinder used by Dietert give due consideration to the problem of short cylinders mentioned above. The machine, howl ever, disregards the need for uniform loading which is now recognized to be an important variable.[28]

An attempt was made to drive Dietert's machine by a motor in order to give approximately the same rate of loading for different samples. The results were unsatisfactory, because it is important to have a uniform rate of loading throughout the entire compression test, and this could not be obtained due to the air contained in the pressure gauge.

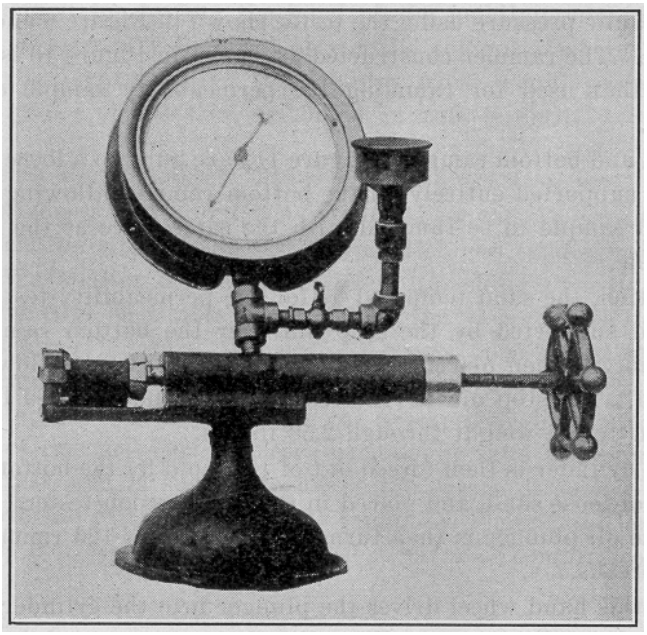

Figure 8. Sand compression strength apparatus.

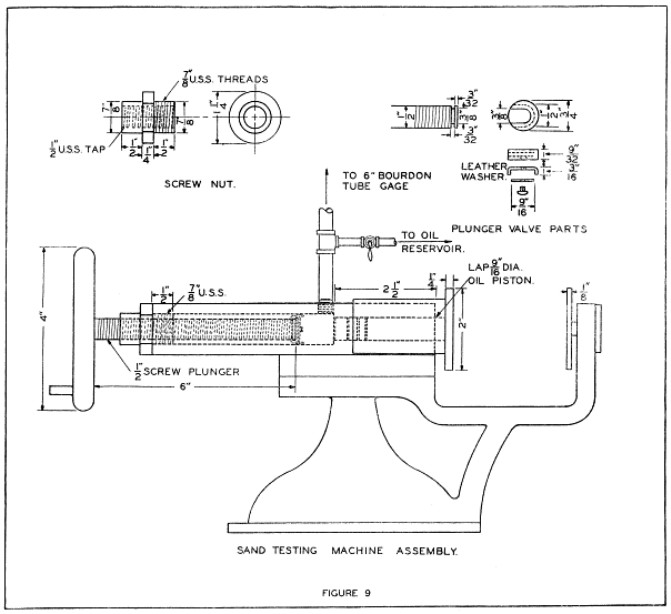

Figure 9. Base permeability of different sized mixtures.

The compressive testing machine developed by Adams[29] loads the sample at a peculiar harmonic rate due to the moving fulcrum between a constant weight at a fixed position and the sample under load. The use of the pantographic method of applying the load to the sand samples involves the application of lateral forces when the compressive load is applied. For these reasons, it seems to contain two important sources of error which eliminated further consideration of Adams' machine for purposes of research.

Various other methods of applying compressive load to sand samples have been described,[30] including a travelling weight apparatus in which I weight is made to move out along a beam applying a load to the sample I , a rate corresponding to the rate at which the weight is moved along the beam.

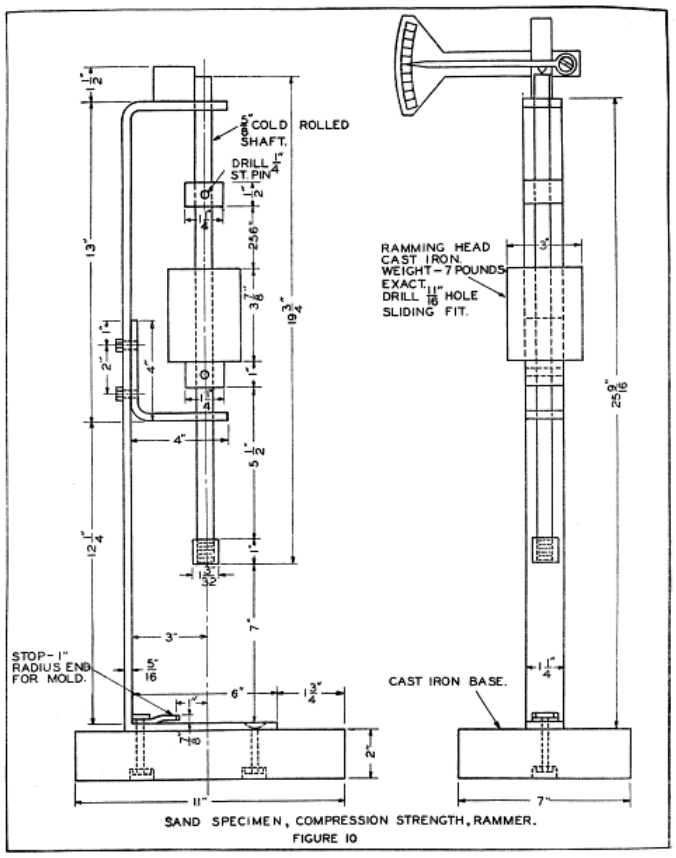

Figure 10. Construction of rammer for compression tests.

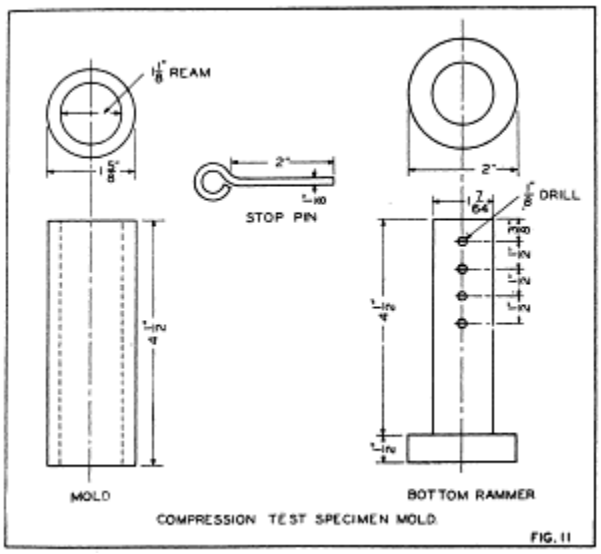

Figure 11. Construction mold for ramming compression test specimens.

[25]Transactions of the American Foundrymen's Association, Vol. 32, page 57. part II, 1924.

[26]Strength of Materials, McGraw-Hill Book Company, New York, 1917, Page 114.

[27]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 24, 1924.

[28]Transactions of the American Foundrymen's Association, Vol. 34, page 521, (1926).

[29]Transactions of the American Foundrymen's Association, Vol. 34, page 448, (1926).

[30]Adams' Transactions of the American Foundrymen's Association, Vol. 34, page 434.

Tensile Strength of Sand

Because the tensile strength of molding sands is always very low, varying between one-half and five pounds per square inch, it is necessary to devise special tensile tests for sand. In many ways a tensile test seems to be the most logical test to employ in indicating the bond strength of the sand, if, by bond strength, we mean cohesion between the sand grains due to the colloidal material and the clay substance covering the sand grains.

A mass of compacted sand will possess considerable strength in compression although absolutely free from any cohesiveness, at least of the kind described. To emphasize this, it might be well to suggest that sand composed of sand grains packed closely together as the bricks in wall possesses a compressive strength approaching that of a solid block of silica or of the mineral of which the sand grains are composed. With the tensile tests, on the other hand, the strength would be due entirely to the adhesion between the sand grains. Although the comparison represents an extreme case, it merely indicates that a tensile strength test may offer important advantages over a compressive or transverse test.

The difficulties which stand in the way of the tensile test are practical rather than theoretical. The Grubb[31] tension cylinder, Figure 12, is two inches in diameter, about five inches long, and is about one sixteenth of an inch thick, in general having about the same dimensions as the cylinder used for preparing the permeability specimen. It is cut cross-wise into two parts, one part two inches long and the other three inches long. The two parts (A and D) carry brass flanges B and C. By fitting a clamp over these flanges the two parts of the cylinder may be held firmly together during the preparation of the sample which is rammed by the permeability rammer. The line of separation of the rings is one sixteenth of an inch higher than the line of division of the cylinder, so that the two parts of the cylinder can be carefully fitted and held accurately in line.

The cylinder is then moved to some apparatus by which the sand is to be tested. The bottom of the cylinder is provided with a bayonette joint which is used to lock it to the base of the testing apparatus. A cylinder top (E) is provided which is locked to the top of the cylinder with a similar joint. A steel wire or other flexible attachment runs from the middle of this top to the testing apparatus and serves to apply the force used in breaking the sand specimen in tension.

When the sand is ready to test the clamps which hold the two parts of the cylinder together are removed, and the lower and upper parts of the cylinder are free to part except with the cohesion of the sand. After a deduction is made for the weight of the top part of the cylinder, cylinder top, and that part of the sand specimen in the upper part, the remainder of the applied force is that required to break the sand specimen. To obtain the unit strength the force so obtained is divided by the area of the cylinder.

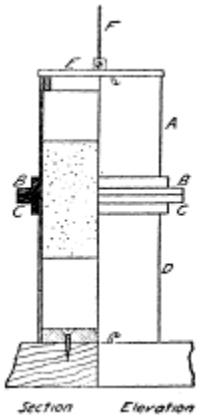

Figure 12. Diagram of Grubb tension cylinder used to test the tensile strength of sand.

Usually the friction and the tightness of ramming are sufficient to hold the two ends of the sand specimen firmly in the cylinder, but in the case of some exceptionally strong sands the specimen may slip out without breaking. To prevent this two shallow grooves are turned in the bottom and top part of the cylinder about a quarter of an inch back from where the cylinder is broken. These grip the sand specimen and prevent it being pulled out.

This tension cylinder has proved satisfactory when carefully handled. It is important that the force pulling the two cylinders apart be applied in the center of the upper cylinder and in a true vertical direction. Otherwise the tensile force applied to the specimen is not evenly distributed over the entire cross-sectional area, and check results are impossible to obtain.

R. W. Kurtz[32] has described a tensile test using the same special sample as for permeability test, breaking the sample in a plane parallel to the direction of ramming which appears to be satisfactory.

[31]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 1, and Transactions of A. S. A., Vol. 34, page 456.

[32]Transactions of American Foundrymen's Association, Vol. 37, page 170, 1029.

COMPARISON OF BOND STRENGTH TESTS

The transverse or "cohesiveness" test is slow, clumsy, and involves more expensive equipment than simple tensile or compressive tests. It yields a bond strength number, which is a function of the density of the sand as well as a complex function of the tensile and compressive strength, and has been found to be roughly proportional to the square foot of the tensile, or compressive strength.

The relation between the compressive or tensile tests is not well understood, but there seems to be a rough

proportionality between the two, as indicated in Figure 13.[33]

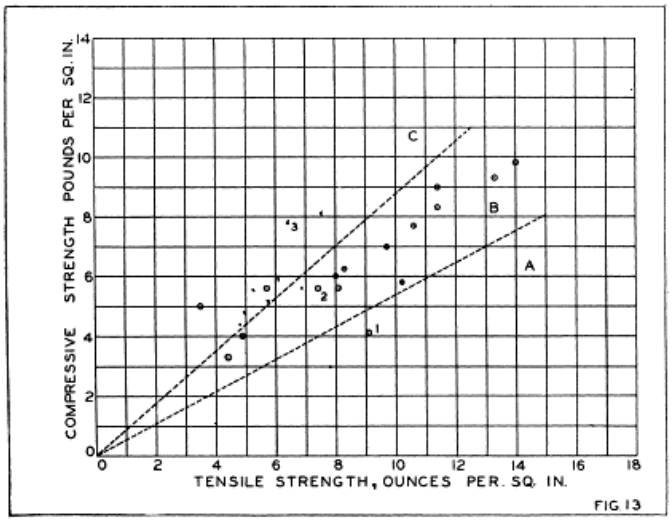

Figure 13. Apparent relation between compressive and tensile strength of green sand.

This relation seems to be satisfactory for sands of similar structure, grain size, colloid content, and temper, but is not valid for comparing radically different types of sand or even the same sands when under different conditions. Those in zone (A) were open sands of high colloidal bond. Those in (B) were natural bonded molding sands from new and some used heap sand. In zone (C) the sands were largely tight sands of low colloidal content, or rather dry samples. For example, sample 1 is of a silica grain bonded with high colloidal clay, sample 2 is a strong heap sand, and 3 a sample of silica flour, all of different moisture content, as indicated below:

Sample	Moisture % Present	Tensile Strength Oz. Per Sq. In.	Compression Strength Lbs. Per Sq. In.	Transverse Strength
1	3.3	9.1	4.1	...
2	5.3	7.4	5.6	202
3	6.0	6.4	7.8	171

The two tests, tensile and compression, do not measure the same properties in these widely different materials.

As molding sand is several times as strong in compression as in tensile strength, we may expect failures in a mold to occur more readily under tensile forces than under compression. Bond strength as recognized by the molder is measured by the force required to pull the grains of sand apart. These considerations indicate that the tensile test is probably a truer measure of bond than any of the other tests. Compression and shear tests are more rugged and generally easier to perform, and because they are roughly proportional to the bond strength, seem to be satisfactory for control purposes and have been widely adopted as measures of bond strength.

Which of the strength tests best indicates the working properties of the sand on the molding floor is still open to discussion. The experience of some investigators[34] indicate that the cohesiveness test is closely related to the working properties of the sand, and measures a property which is one of the determining factors in the production of dirty castings. Others[35] "have definitely determined that the compression test offers a better means of checking the strength characteristics of the and consequently it was substituted for the cohesiveness of bond as routine control check on the sand."

[33]A. A. Grubb, Instruments, January 1928; and Transactions of American Foundrymen's Association, Vol. 32, Part II, page 14.

[34]Wolfe and Grubb, Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 1.

[35]Harrington, Wright and Hosmer, Transactions of the American Foundrymen's Association, Vol. 34, page 307, 1926.

AUTOMATIC PRECISION STRENGTH TESTS

The compression and the tensile test are the only two theoretical sound tests so far described and suitable for use in testing sand. An automatic machine suitable for either test was constructed with the following points in mind:

1. No initial loading of the sample
2. Freedom from impact forces
3. Constant rate of loading
4. Automatic operation, including stopping of the machine and indication of the breaking load.
5. Accurate and sensitive to less than one gram.

Testing Machine

The machine assembled is shown diagramatically in Figure 14, and in Figure 15. Its principle is that of a simply supported beam with a weight which is caused to travel at a constant rate between the supports of the beam.

By counterpoising such a beam and weight on one of the supports and making the weight travel an appropriate distance before any load is applied on the other support, no initial load is put upon the sample. The sample is placed almost in contact with the piston face applying the pressure, and as the sensitivity of the machine is of the order of one gram the initial load or shock of the impact force is negligible. As soon as the moving weight crosses the point where the load begins to be applied to the sample the piston comes in contact with the sample and the machine becomes a beam simply supported at its two ends. If the weight is driven at a constant rate, the load increases at a constant rate. This is accomplished by an electric motor through a reduction gear and chain drive, which eliminates the personal factor.

As the weight (A) travels along the beam (C), there comes a time when the sample begins to give way, finally to break. The recording of the pressure which caused a certain amount of deformation is easily done by adjusting the electrical contact (T) at the end of the beam. This electrical contact closes the circuit which operates a ratchet dog (J), and relay, not shown, in the rear of solenoid (G), which in turn operates an iron clad

solenoid (G), the function of which is to pull away one face of friction clutch (H). By means of this mechanism the screw (B) propelling the weight (A) is made to stop when the sample breaks.

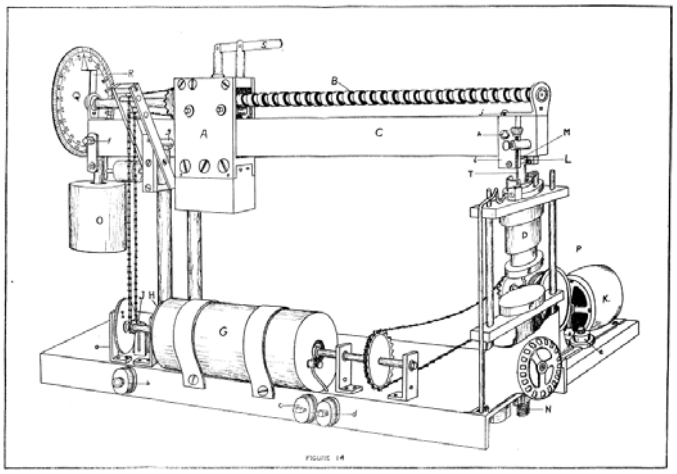

Figure 14. Construction of automatic testing machine.

Most samples break before being deformed more than two-tenths of an inch. The effective length of the beam is 25 inches so that the total deflection of the beam before the sample breaks is less than ½ of one degree. The total change in effective weight of the traveler at any time over any distance traveled is about one part in a hundred thousand. Even this negligible error can be almost wholly overcome by allowing the initial position of the beam to be one-half the distance of the probable deflection above the horizontal.

The pressure is transmitted from the beam to the sample under the piston by a rolling point contact (M) and a vertical ball bearing race. The piston (L) is of hardened tool steel ⅝" in diameter fluted with six equi-spaced lengthwise ball races. The balls ride against the fluted piston (L) and the wall of the hardened internally ground bushing (D), their clearance being less than three ten-thousandths of an inch. Two sets of balls supported at intervals of two and a half inches along the fluted piston rod near the top provide a means of suspending the piston and piston rod on the knife edges at the end of the beam.

Over the top of the piston rod (L) there is slipped a brass ferrule, the internal diameter of which is about half a thousandth of an inch greater than the ball bearing which rests in a ground groove in the top of the piston rod running parallel to the beam at right angles to the hole from which the saddle suspension is pinned to the piston rod. By means of screws at the top of the saddle, the hardened knife edge sockets are adjusted so that there is a clearance of one-thousandth of an inch between the top of the ball and the bottom of the beam. As the weight is supplied the beam comes down on the hardened steel ball, and as the beam tends to shorten or lengthen the beam rolls over the top of the ball, so that the pressure is transmitted directly to the piston face and is the same at any point on the piston face.

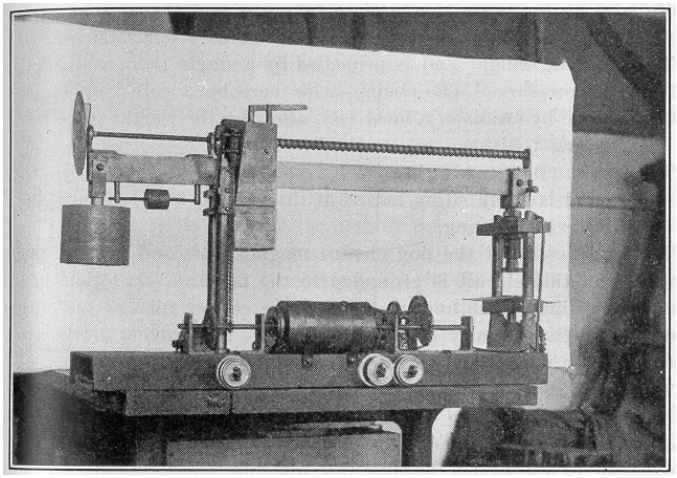

Figure 15. Automatic machine for precision strength tests.

The beam is supported on a hardened steel knife edge (g). The knife edges (fgh) extend through the beam and are fastened by means of set screws.

The pivotal support is further reinforced by having the hardened end of the knife edge rest against a small steel ball bearing which is appropriately caged so as to give a rolling point contact to the end of the knife edge as the beam tips, and to take any end thrust that might bet developed by the chain drive of the screw which propels the weight.

The traveling weight (A) is propelled by a single tooth which project into the screw thread (B), being held there by a coiled spring, which may be raised by means of a lever (S), allowing the weight to be returned to its starting position.

The screw (B) machined from ¾" cold rolled steel has two threads per inch, and is mounted by means of three small ball bearings (a), one of them a thrust bearing.

The relay coil and the dog electro magnet are connected in parallel. One side of this circuit is grounded to the machine, the other is led to the battery line switch and up through the copper tube at the corner of the base to the mercury cup binding post. The battery leads are connected to one pole of the switch and to the machine base.

The 110 volt D. C. line is connected through the relay contact points to the solenoid winding and the switch (b) which is on the side of the machine. Across the relay contact points a snap switch (c) is connected. This switch breaks the solenoid current thus preventing undue burning of the relay points due to arcing caused by induced currents.

The motor is controlled by a snap switch (e) in one side of the 110 A. C. volt current supply line.

The traveling weight is pushed back, the counter poise weight adjusted by means of lead shot poured into its centrally cored hole, the battery current is turned on, the 110 volt D. C. switch is closed and the relay contact switch is closed which brings the face plate of the clutch back with a sharp click compressing the spring on the

shaft. The motor switch is turned on. One face of the friction clutch is now revolving. The relay contact switch is opened. The spring forces the plunger and clutch face plate forward against the still face plate of the jack shaft clutch. The jack shaft is revolving. The chain slowly trundles over the sprockets, the tooth of the traveling weight jumps onto the thread, the screw revolves, the weight moves out along the beam which suddenly dips downward. As soon as the electrical contact is made by (T) at the mercury cup, the electro-magnetic dog stops the jackshaft and the functioning of the relay causes the driving face of the clutch to be pulled back. Switch (d) is turned on to prevent relay contact points from arcing due to induced currents otherwise produced by lifting the beam and breaking the contact between (F) and the mercury cup. When the machine is to be stopped the switches are turned off in the following order: e, b, c, d.

Calibration. A light metal saddle and a half inch steel ball is counter poised on a balance for large loads sensitive to ¼ gram. The middle is made to swing from the balance under the upper crushing face. A ½" steel ball is placed between the saddle face and the upper crushing face. The position of the saddle face and ball are adjusted by means of the screws at the ends of the saddle so that the light can just be seen between the metal ball and the crushing face when the beam is in the "up" position. A weight is placed on the opposite balance pan; the machine is started and allowed to trip the balance, stopping the screw, traveling weight, etc. The position of the weight on the beam is marked temporarily and the reading on the disk at the end of the screw is noted. The operation is repeated several times for each point obtained; the weights placed on the balance pan being recorded, the disk readings noted and the beam marked with positions of the weight. It was found that scarcely any variation in the loading could be observed, that a divider used to measure the distance between the marks on the beam caused by like increments of weight on the balance pan needed no adjustment. The weight of the traveler was so adjusted that the reading was ⅔ of the actual load; that is, the reading multiplied by 1.50 gives the actual load in grams. After several months of more or less continuous use the calibration of the machine did not perceptibly change.

The Sand Rammer

The rammer used in preparing specimens for compression tests is an adaptation of that described by Dietert (Figure 10).

The cast iron head weighing exactly seven pounds slides on the rod in the manner described, but stops pinned to the steel rod regulate the movement of this head to 1.95 inches instead of 2.56 inches. The sand is placed in the cast iron cylindrical mold 1⅛" internal diameter on a steel pedestal instead of the bottom rammer used by Dietert. The frame of the rammer is secured to a piece of cast iron 21" x 18" x 3", both flat sides of which are smoothly machined to act as an anvil for the ramming (Figure 15a).

An indicator consisting of a brass frame on which is pivoted a light beam carrying a knife edge point one inch from the pivoted end is used to measure accurately the height of the rammed sample. The scale at the end of the indicator beam is calibrated from 1.75" to 2.20" by hundredths of inches using Johnson gauge blocks.

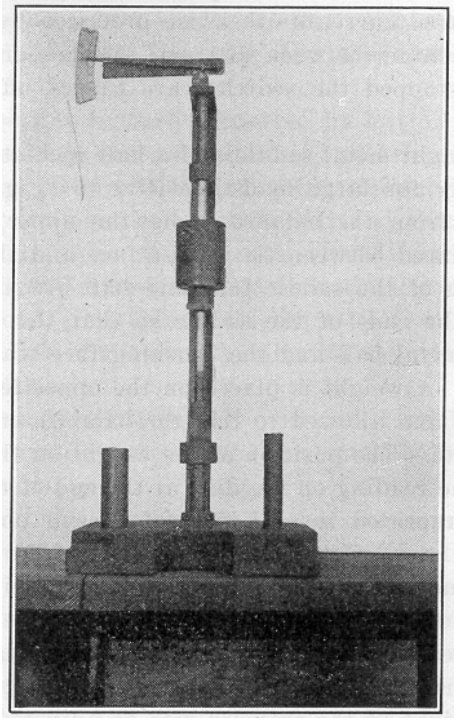

Figure 15a. Sand rammer for compression test.

Bond Strength Testing Procedure

The cast iron collar of the pedestal of the ramming device is adjusted so that the cylinder resting on it would contain enough sand to form a sample about two inches high by 1⅛" diameter (about 38-44 grams). The sand carefully tempered as has been described is transferred to the forming cylinder on the pedestal and the weight of the steel guide rod and rammer head allowed to rest momentarily on the top of the sand while the weight is raised by hand to the upper stop pin. As the weight comes in contact with the upper pin it is allowed to fall freely. This is done three times for each sample, care being taken that during the ramming operation the face of the rammer is always in contact with the face of the sample.

Directly after ramming, with the rammer face still resting on the sample, the beam of the indicator is swung into position so that the knife edge comes in contact with the top of the guide rod, and the height of the sample is read to the nearest .005" from the scale and recorded.

The sample is rammed from one end only. The reason for this is to eliminate any possibility of error in preparation that might be due to any small misalignment of the sand cylinder with top and bottom rammer which might occur if the sand were rammed from both ends causing the three to bind and stick or otherwise absorb the kinetic energy which should go into compressing the

sand sample to the required dimensions, preliminary work showed this precaution to be a refinement necessary for consistent results. Reversing the ends of the samples rammed from one end only in the testing machine showed no difference in breaking strength.

The samples are stripped from the cylindrical mold by lifting the mold off the pedestal and pressing the sample out of the mold on a long steel pedestal or column of like diameter. The sample is grasped between the thumb and forefingers and the excess sand blown off each end.

The sample is then placed on the movable face plate (F) of the compression machine (Figure 14). The motor having been started and switches (b.c.d.e.) closed, the position of the sample is adjusted to bring it just into contact with the upper surface (E) by means of the hand wheel raising or lowering (N). Switch (d) is snapped off setting the weight in motion. When the sample is broken the weight is automatically stopped indicating the breaking load by its position. The crushing plates are carefully wiped free of sand, and opened by turning the hand wheel.

The cylindrical ramming mold is carefully cleaned by drawing a clean cloth through it and any sand that might be near the pedestal or on it is removed after each determination.

Accuracy of Results

The compressive strength of sand samples prepared and tested in the manner described show a maximum deviation between extreme values of:

16.4 grams on samples of 683 grams average strength per sq. in. or 2.4 percent.

9.75 grams on samples of 960 grams average strength per sq. in. or 1.01 percent.

36.0 grams on samples of 2440 grams average strength per sq. in. or 1.46 percent.

and a maximum deviation from the mean of five or six check determinations of:

9 grams on sample of 683 grains average strength per sq. in. or 1.25 percent.

9 grams on sample of 960 grams average strength per sq. in. or 0.9 percent.

23 grams on sample of 2440 grams average strength per sq. in. or 0.94 percent.

Although such accuracy is probably not necessary in industrial routine testing, it is frequently necessary to determine slight differences in careful research work. The machine was designed for this purpose and has proved entirely satisfactory.

THE CAUSE OF THE BOND IN MOLDING SANDS

The Effect of Clay and Silt

Little definite information is available regarding the actual cause of the bond in molding sand. It is generally recognized that the bond of the sand is due to clay or colloidal matter surrounding the sand grains, and serving as a bond between the sand grains tending to prevent failure when under a tensile test. Clearly the bond is due to some surface condition of the sand with clay or colloidal matter serving as a bond. Generally the adhesion is greater when the clay contained in the sand has a high plasticity. This indicates that the bond in molding sand maybe dependent in a large measure on the same properties as determine the plasticity of clays. But an accurate knowledge of the factors causing plasticity is apparently not available at the present time.

Moisture

As *moisture* plays a very important part in developing the natural bond of the sand, it is necessary to carefully control the moisture content of sand being tested or when used in foundries. Any sand when moist, will show some bond strength due to the surface films of water adsorbed on the sand particles. And it seems that the bond in natural molding sand is due to a strengthening of this water bond by colloidal material adsorbed on the sand surfaces, and by the small particles of silt and clay which act as a re enforcing medium to the colloidal matter between the sand grains.

The fine particles classed as silt and clay have a much greater surface than the larger sand grains and consequently require more water for the proper wetting of the sand particles and the development of the colloid structure, and have a higher bond strength due to the greater surface which can be water bonded. Likewise those sands which contain a larger amount of clay with a practically constant silt content seem to possess a greater bond strength, other factors being equal.

Mulling

It has been conclusively shown both in laboratory test and in actual plant operation, that the bond of a sand may be increased by adding clay material to the sand. The increase in bond can be greatly improved if the mixture of sand and clay is then mulled for a relatively long time. The maximum[36] bond of sand clay mixtures was obtained only after some fifty to seventy-five minutes in the mulling machine. The exact effect of this mulling is not known, but it must serve not only to mechanically mix but also to bring the sand and the clay into such intimate mixture that the colloid matter in the clay may have an opportunity to be adsorbed to better advantage on the surfaces of the sand particles.

Mulling may also tend to develop an increased percentage of colloidal matter in the clay and sand mixture, due to its fine grinding action. This is true if a natural sand could be improved by mulling. In the formation of molding sands, as described in Chapter I, the colloid matter and the clay are actually deposited on the surface of the sand grain, and mulling could not improve the distribution of such material. So far as is known no test of the effects of mulling on the bond of a fresh natural sand has as yet been reported, and further

work is necessary before we can estimate what effect mulling has on the constitution of the molding sand.

[36]Wolfe and Grubb, American Foundry men's Association, Vol. 32, Part II, page 1.

Colloidal Iron Oxide

As pointed out by Littlefield,[37] the surface of the sand grains is a very important factor.

"Clay does not adhere to the smooth surfaces of chert or quartz grains. The surfaces of clean quartz grains may be exposed by breaking a damp lump of clay and quartz sand; but if the quartz grains are coated with a film of limonite, a break in a damp lump will not reveal the presence of the grains, as each grain has a coating of clay which adheres more tightly to its surface than to the body of the clay. The increase in bond strength which is affected by this grain coating is large—so large, in fact, that the successful synthetic manufacture of molding sand of low refractoriness from clean sand and clay is commercially impracticable".

The importance of the limonite or colloidal ferric oxide on the bond of molding sand has been recognized for some time, and it has usually been taken for granted that it is impossible to duplicate even approximately that peculiar condition on the surfaces of natural molding sands by any artificial means.

Condit[38] states that the hydrated iron oxide films on sand and clay particles are formed by precipitation of iron salts from surface water.

In direct contrast to Condit's views, Gordon[38a] accounts for the presence of colloidal gel coatings on the silicate particles as formed by decomposition of the sand grains themselves.

Boswell[39] reports the beneficial effects of iron oxide as a binder in the British red sands.

"Good moldings should not 'go dead'; that is dehydrate too readily after metal has been cast in them. Iron oxide readily hydrates again, unlike clay which may be 'porcellainized' by heat.

"The distribution of the bond in naturally bonded sands is ideal. Each grain of quartz is coated with a thin pellicle of ferric hydroxide or ferruginous clay. Water skins cannot hold on to clean quartz, but each coated grain assumes the skin of water, which with its neighbors constitute the enormously strong 'green bond' of the sand.

"It is noteworthy that in the West European sand the higher the percentage of ferric hydroxide the greater is the transverse strength in the sands. In the case of the sand from South Africa containing 4.81 percent of ferric hydroxide, the molds produced were of extraordinary strength and toughness."

Hanley and Simonds[40] express their belief that the majority of the well bonded molding sands of this country owe their bonding qualities to the presence of colloidal hydrated ferric oxide, as follows:

"In the study of many sands surprising results are obtained in connection with the effect of iron oxide on the bonding property . . . . . Just what composes the 'clay substance' (bond) in molding sand is not generally understood, and the following analyses of the bonding material after it is separated from the sand may serve to clear up this point".

	New Jersey Sand	Ohio Sand	New York Sand
Silica	41.70	33.65	38.88
Iron Oxide	14.27	28.88	24.67
Alumina	25.40	18.15	22.50

Bean[41] considers iron oxide detrimental in molding sand when present in small amounts. His views are criticized by Shaw.[41a]

Moldenke considers iron oxide bad, but admits to a limited degree its beneficial action on bond.

Boswell[42] notes that molding sands fall into two classes: naturally bonded sands which contain ferric hydroxide or certain silicates, and high silica sands which must be bonded artificially with such substances as sugar, dextrin, molasses, oil, or sulphite lees. He[43] states that the ferruginous bond improves the life of the sand and assists in the production of a smooth sound surface to the casting, particularly in the case of steel. It should be noted that this view is practically the opposite to that held by Moldenke and Bean.

Kennedy[44] calls attention to the fact that all attempts to produce artificial molding sands with the same bond as natural sand have been unsuccessful because of improper distribution of clay around the grains, giving a sand lacking in durability. He suggests that these failures are due to a lack of knowledge of the properties of iron oxide as a binder, and of ability to coat sand grains with the colloidal hydrated iron oxide.

Although it has been recognized for some time that colloidal ferric oxide films might have an important influence on the bond strength of sands, no quantitative data have been presented to show the effect of such films, or to account for the bond in molding sand in terms of such films. Accordingly a thorough investigation of the effect of colloidal ferric hydroxide was undertaken as part of this report.

Quantitative data showing the relation of colloidal ferric oxide adsorbed on the sand grains and on the clay bonding material to the strength of bond in the molding sand was obtained and the successful preparation of synthetic molding sand was accomplished in the course of this work done on Michigan sands. The effect of colloidal iron oxide on the bond of molding sands has been determined by analytical methods on natural sands; and by synthetic methods successfully reproducing the bond of natural molding sand by the proper combination of clean unbonded sand or silica, kaolin, and ferric hydrosol.

[37]Bulletin 50, Illinois Geological Survey, 1925, page 23.

[38]Transactions of the American Foundrymen's Association, Vol. 21, pp. 21 to 27, 1912.

[38a]Gordon. Colloid Symposium, Chemical Catalogue Book Co., p. 114, (1924).

[39]Engineering 108, pp. 418-20, 464-66 (1916).

[40]Foundry 48, pp. 722-4 (1920).

[41]Bean—Transamerican Foundrymen's Association, 36, p. 419, (1917).

[41a]Shaw—Trans. Eng. Ceram. Soc. 13, (1912-14).

[42]Boswell—Foundry. 47, pp. 148-50, (1919).

[43]Boswell, Jour. Inst. Metals, 22, p. 292, 1919.

[44]Kennedy—A summary of the Literature on Molding Sand, American Foundrymen's Association Bulletin.

Analytical Determination of the Factors Causing Bond in Natural Molding Sand

Fresh Sand. A fresh sample of Albany molding sand was carefully dried in an air oven at a temperature between 105 and 110 degrees centigrade, thoroughly mixed and quartered to yield one sample of two thousand grams, which was preserved in a glass jar. This sand was tested for bond strength in compression and permeability by the method described with the results given in Table XII, and plotted as a function of moisture content in Figure 16, and Figure 17 as curve N.M.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.3	1.760	122.9	29.2
5.2	1.906	137.6	30.1
7.14	2.064	144.15	31.8
9.82	2.137	148.2	29.9
11.83	2.098	146.4	27.0

Table XII. Properties of the Natural Molding Sand.

The Natural Base-Material was prepared from the natural sand by removing all of the clay, silt, or loam surrounding the individual sand grains, which could be removed by washing and siphoning with water.

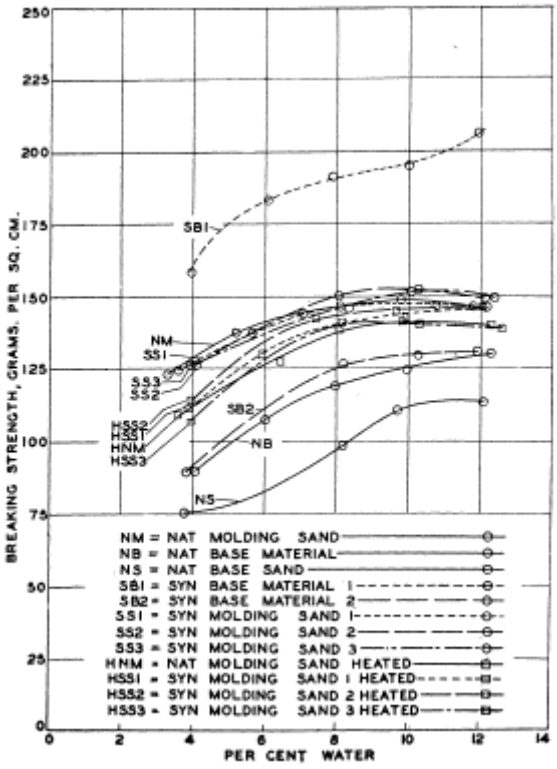

Figure 16. Compressive strength as a function of water content.

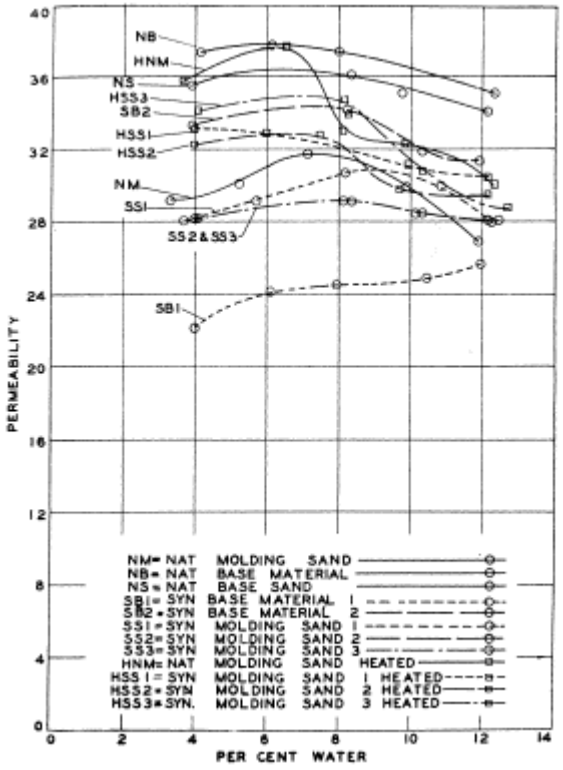

Figure 17. Permeability as a function of water content.

The so-called "clay substance" was removed from the natural Albany molding sand by repeated washing and shaking with tepid distilled water. Some 40 pounds of sand were distributed in clean quart Mason jars, 1/2 pound of sand to each jar. Twenty jars of sand were treated at one time. Each jar of sand was filled with distilled water to about two inches from the top. The jar was tightly stoppered, thoroughly shaken, and allowed to settle until the last one of the jars had been so treated. The water was then siphoned out of the first jar, care being taken to have the end of the 3/16" rubber tube siphon at least 3/4" above the level of the sand layer that has settled out. The water suspension of silt, clay, and loam, siphoned off was caught in an enameled pan and transferred to a steam jacketed Duricon kettle. This operation was repeated continuously for about two weeks, at the end of which time the water above the sand could be seen to be perfectly clear. In the meanwhile all the washings had been evaporated to dryness, collected and weighed. The silt and clay so collected constituted about 13 percent of the original dried sample. A screen analysis indicated that all this material passed through a 270 mesh sieve.

The Natural Base-Material of the molding sand was washed out of the jars into an enameled container, excess water decanted through a filter paper on a Buchner funnel, the sand so caught returned to the contain. The natural base-material was air dried, then dried for one hour at 105°C. and mixed for testing.

The screen analysis of the natural base-material made by sifting 100 grams of the material obtained by quartering for 30 minutes in a Rotap machine was as follows:

Screen Analysis

Mesh	% On	Mesh	% On
50	0.028	140	20.582
60	0.268	200	40.600
70	0.422	270	25.950
80	0.235	Pan	11.990
100	0.522		

The bond and permeability are given in Table XIII, and Figures 16 and 17.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.11	1.274	88.9	37.3
6.03	1.538	107.5	37.7
7.97	1.704	119.0	37.5
9.97	1.782	124.5	36.4
12.28	1.865	130.25	35.2

Table XIII. Properties of the Natural Base-Material.

It is evident that the bond strength of the sand has been greatly decreased and the permeability increased by removing the so-called clay substance. If the clay substance is entirely responsible for the bond of the sand further washing of the sand particles would have no effect on the bond strength or permeability of the natural base material. Further tests were made in the preparation of *the natural base sand* from *the natural base material*.

The Natural Base Sand was prepared by removing the adsorbed material from the natural base-material. A large portion of the natural base-material was treated with 1 percent caustic soda solution and shaken, then washed with water, and digested with hot 1-1 HCl to dissolve any film of hydrated oxides. The sand was washed repeatedly by decantation at first alternately with hot dilute acid and hot distilled water. Finally with hot distilled water until the washings were free from acid. The sand after this treatment is hereafter referred to as the *natural base sand*. This material was kept under distilled water which was changed frequently until no more acid, as determined by the colorimetric hydrogen-ion method diffused into the water. The base-sand was then collected and dried at 110°C. Its general appearance had changed from dull greenish brown to a light gray shot with sparkling bits of mica.

The Iron Oxide Removed from the Base Material by hot 1-1 HCl was determined and found to be 2.6 percent of the base material. The total was 0.0272 grams—per gram of sample of 2.72 percent. This analysis indicated that practically all of the material removed by the HCl was iron of one form or another.

Bond and permeability are given in Table XIV, and in Figures 16 and 17.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.85	1.081	75.5	35.6
8.25	1.402	97.9	36.2
9.70	1.581	110.5	35.2
12.09	1.617	113.0	34.2

Table XIV. The Properties of the Natural Base-Material.

Results. Adsorbed ferric hydroxide on the particles of Albany sand contributes in no small measure to the bond strength of Albany sand. The percentage reduction in bond strength at that moisture content giving the maximum bond is practically 12 percent in each case, when the clay substance (13 percent) is removed from the natural sand, or when the adsorbed ferric hydroxide (2.7 percent) is removed from the natural base material. The permeability of the natural base material is decreased by the removal of the adsorbed ferric hydroxide. This is probably due to the adsorbed colloidal matter on the sand grains swelling on the addition of moisture and effectively increasing the size of the sand grains, thereby increasing the permeability.

Although the above analytical procedure leads to results which clearly indicate the importance of adsorbed ferric hydroxide in developing the bond of a natural molding sand, conclusive proof of this fact can readily be obtained if artificial ferric hydroxide can be readsorbed on the sand grain, restoring the properties of the natural base material and a synthetic clay substance added to this synthetic base material, thereby restoring in all essentials the original properties of the natural molding sand. In this attempt to duplicate artificially the properties of a natural molding sand, only pure materials were used.

SYNTHESIS OF MOLDING SAND

In order to duplicate the properties of this natural base-material from the base-sand it is necessary to restore in all essentials the original surface conditions to the base sand. This was accomplished by adding the base sand a synthetic iron hydrosol in place of the natural colloid removed, thereby forming a synthetic base-material.

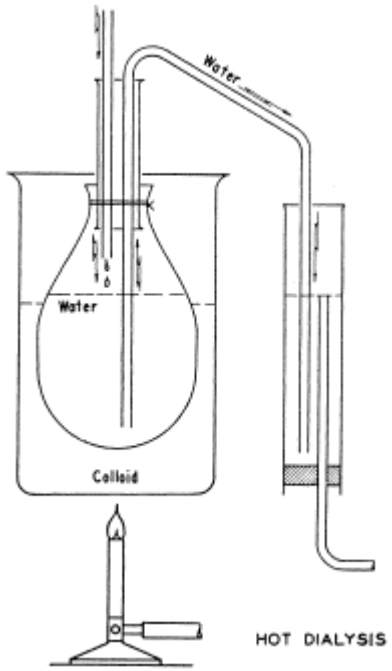

Figure 18. Diagram showing apparatus used in dialysis.

For the duplication of the properties of the natural molding sand from the natural or synthetic base-material

it is necessary to restore the bond material in all essentials. This was accomplished by adding to the natural base-material and to the synthetic base-material, synthetic bond materials. In preparing the synthetic base-material and the synthetic molding sand, silica, kaolin and an iron hydrosol were used.

Preparation of Silica. Two hundred pounds of pure fused silica ground to pass 100 mesh was procured from the Thermal Syndicate Ltd. of Brooklyn, N. Y. The principal impurity of this material was finely divided particles of iron, just enough so that when the silica was treated with dilute acid, a trace of iron was found by the sulphocyanate test.

A slight alkalinity was also noted in the first portions of wash water from the silica.

About 100 pounds of silica was washed by decantation with conductivity water until the washings showed no trace of their original alkalinity. Incidentally this treatment removed most of the finely divided iron and some dust. The silica was thrown on to a large Buchner funnel, where a large portion of the water was removed by suction. It was placed on a large block tin tray, air dried, then dried at 110° C.

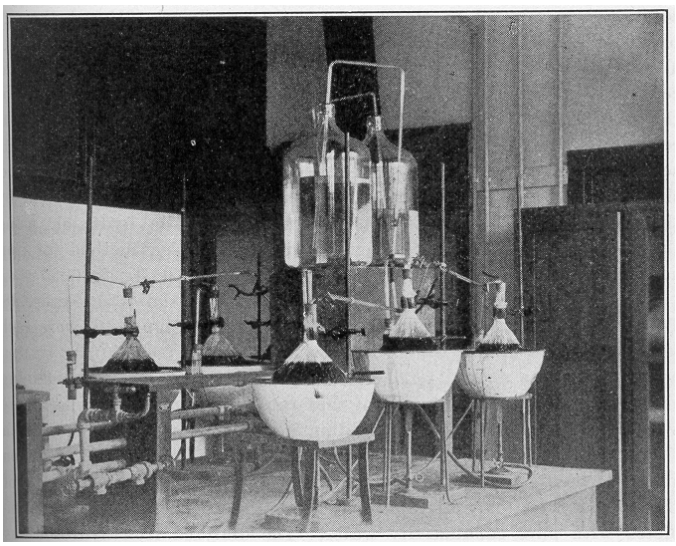

Figure 19. Battery of three dialyzing units.

After drying, the silica was thoroughly mixed and three samples of 2,000 grams each sealed in glass jars. The remainder of the silica was kept in a clean paper lined burlap sack from which it was drawn as needed. A portion of this sand was sifted through a 270 mesh sieve to provide fused silica for the synthetic "bond-material" No. 1.

Preparation of Kaolin. A quantity of Merck's Kaolin and also ten pounds of a non-plastic kaolin, furnished by the research laboratory of the Norton Company through the courtesy of Messrs. Kilpatrick and Beecher of that organization, were washed by decantation with distilled water, dried at 105-110°C. and pulverized to pass 270 mesh.

Preparation of Iron Hydrosol. The iron hydrosol or suspension of hydrated iron oxide was prepared by a method similar to that of Neidle and Barab.[45]

90 grams of c.p. $FeCl_3$ $6H_2O$ was dissolved in 400 cc. H_2O. To this added dropwise with constant stirring 150 cc. of ammonium hydroxide solution made by diluting 35 cc. of 0.9 sp. gr. NH_4OH to 150 cc. solution was allowed to stand for twenty-four hours, filtered through paper on a Buchner funnel, diluted to two liters, and dyalized through a collodion bag. After twenty-four hours of cold dialysis, the dialysis was continued at 70°-90° C. The collodion bags were changed each day for the first week and every other day thereafter until the dialysis was completed. This point was considered to be reached when 500 cc. of the solution from the interior of the collodion bags evaporated to 50 cc. showed no test for iron by the sulphocyanate method or for chlorine by the usual silver nitrate test. The analysis of the hydrosol, using the method of Thomas[46] for chlorine and a gravimetric method for iron as iron oxide, indicated the ratio: Fe_2O_3 : FeCl = 15.0 : 1.

The general scheme of the dialyzing operation is shown in Figure 18. Two batteries of three dialyzing units in parallel, Figure 19, were each fed from a five gallon water bottle. The rate of feed during sixteen hours a day was about 1½ to 2 liters per hour, and for the remaining eight hours approximately half of that rate. The outer containers were Vollrath enameled steel pans holding about six liters. Other than at slight stain on the enamel these pans showed no marked deterioration after one month's continuous use for this purpose. At the beginning of 1 the operation ordinary distilled water was used. The dialysis was completed with pure conductivity water. The dialyzed iron hydrosol was stored in glass bottles kept in a cupboard away from the light.

[45]Jour. Am. Chem. Soc. 39, 79 (1917).

[46]Thomas—Jour. Am. Chem. Soc. *45*, 2533 (1923).

Adsorption of the Iron Hydrosol. In preparing the synthetic bonds and sands, the kaolin and sand were weighed out with an excess of water, then mixed thoroughly with the proper quantity of the iron hydrosol. For the sand sufficient hydrosol was used to give an Fe_2O_3 content off 1 percent; for the clay the Fe_2O_3 content was 0.44 percent. The mixture I of sand and hydrosol, or clay and hydrosol, was evaporated to dryness at or about 100° C. in a water bath, then dried at 105° C. for one hour, and the clay broken up to pass a 270 mesh sieve. This dry synthetic mixture was put through a sieve, one size larger than the largest grain of sand in the mixture, four times. The dry material was further mixed by spreading on a block tin platter and stirring systematically with a tin spoon, after which the synthetic material was used directly in making up sand samples for testing.

Synthetic Bonded Materials No. 1 and No. 2. A chemical analysis of the clay-like bond material washed out of the molding sand was made. It will be noted that the water

of composition of the kaolin is deducted from the total loss on ignition in the rationalized analysis.[47] [48]

	Chemical Analysis	Rationalized Analysis
Alumina (Al_2O_3)	6.20%	15.4% Kaolin
Iron Oxide (Fe_2O_3)	2.60%	2.6% Fe_2O_3
Silica (SiO_2)	86.10%	78.86% SiO_2
Loss on Ignition	3.6%	1.6% Loss on Ignition
Lime (CaO)	.11%	.11%

Table XV. Analysis of Natural Bond Material.

Synthetic Bond No. 1. From this analysis, assuming that all the alumina was in the form of kaolin and that both kaolin and silica grains were coated with hydrated iron oxide, a similar synthetic bonding material was made up of the proper amounts of fused silica and kaolin ground to pass 270 mesh and carrying adsorbed ferric hydrate. This material, referred to hereafter as synthetic bond No. 1 was air dried, then dried at 105° C. for one hour and preserved in stoppered bottles until used.

Synthetic Bond No. 2. Another bond material in which the fused silica passing 270 mesh was replaced by natural base-sand of the same size obtained from the original Albany molding sand was prepared. These grains were also coated with a film of hydrated iron oxide. The synthetic bond material so obtained will be referred to hereafter as synthetic bond No. 2. It was air dried, then dried at 105° C. for one hour, and preserved in stoppered bottles until used.

Synthetic Base-Material No. 1. The synthetic base-material No. 1 was made by adding to ground, fused silica of approximately the same screen analysis as the natural base material, in the manner described, 1% of hydrated iron oxide. The bond and permeability results are given in Table XVI and plotted in Figures 16 and 17.

[47]Mellor—Trans. Eng. Ceram. Soc. *13*, (1913-14).

[48]Samoylov—Bulletin de l'Academic Imperial des Sciences de St. Petersburg VI Ser. 31, (1909).

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.97	2.16	158	22.2
6.09	2.60	183.5	24.2
7.93	2.72	191.5	24.6
10.04	2.77	195.0	25.0
11.93	2.92	206.0	25.7

Table XVI. Properties of Synthetic Base Material No. 1.

Synthetic Base-Material No. 2. The synthetic base-material No. 3 was made by adding to the natural base-sand in the manner described 1 percent of hydrated iron oxide.

The bond and permeability are given in Table XVII, and plotted in Figures 16 and 17.

The bond strength of the synthetic base material prepared from the 1 natural base sand and synthetic colloidal ferric hydroxide is practically the same as that of the natural base material. At 12 percent moisture content, that giving the maximum bond strength, the synthetic base material No. 2 is identical with the natural base material. At lower moisture contents the synthetic material has a slightly higher bond strength. The bond strength of a synthetic base material No. 1, prepared from crushed silica rock or quartzite is much higher, due evidently to the differences in grain shape between the sharp crushed silica rock and relatively rounded natural sand from the Albany molding sand district.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.85	1.274	88.9	33.4
8.2	1.786	125.6	34.2
10.31	1.852	129.4	32.0
11.93	1.885	131.7	31.5

Table XVII. Properties of Natural base Sand Plus 1% Hydrated Iron Oxide, Synthetic Base Material No. 2.

The permeability of the synthetic base material No. 2. is less than that of the natural base material, or of the natural base sand. The differences, however, are not marked and are probably due to the fact that ferric hydroxide adsorbed on the natural base sand differs in some physical properties from natural ferric hydroxide originally contained in the sand. This contention is borne out by the fact that one percent of the synthetic ferric hydroxide is equivalent to 2.6 percent of natural ferric hydroxide in increasing the bond strength.

The next step is to reproduce the properties of the natural sand by adding to the synthetic base material and to the natural base material synthetic bond or clay substance.

SYNTHETIC MOLDING SANDS

The synthesis of molding sands having properties similar to those of the natural sand has been attempted in three different ways. Because the properties of the synthetic base material No. 1 were no different from the natural base material no synthetic molding sand was prepared from synthetic base material No. 1.

Synthetic Molding Sand No. 1 was prepared by adding 13 percent of synthetic bond material No. 1 to the natural base material.

Synthetic Molding Sand No. 2 was prepared by adding 13 percent of synthetic bond material No. 1 to the synthetic base material No. 2.

Synthetic Molding Sand No. 3 was prepared by adding 13 percent of synthetic bond material No. 2 to the synthetic base material No. 2.

PROPERTIES OF SYNTHETIC MOLDING SAND

The properties of these three synthetic molding sands are given in Tables XVIII, XIX, XX, and Figures 16 and 17.

The general agreement of the data on the synthetic molding sand with that of the natural molding sand is extremely good, and indicates that the physical strength of the natural molding sand has been substantially duplicated by that of the synthetic molding sand.

Percentage H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.65	1,786	124.7	28.1
5.67	1 965	137.2	29.2
8.15	2.095	146.2	30.8
10.8	2 097	146.4	30.0
12.2	2.095	146.2	28.0

Table XVIII. Properties of Synthetic Molding Sand No. 1.

Percentage H_2O	Breaking Strength in Compression		Permeability
	Lb./Sq. In.	Gms./Sq. In.	
4.06	1.912	126.1	28.2
8.11	2.138	150.0	29.2
10.33	2.190	152.5	28.6
12.17	2.123	149.0	28.2

Table XIX. Properties of Synthetic Molding Sand No. 2.

Percentage H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.98	1.806	126.1	28.2
8.37	2.077	146.7	29.2
10.08	2.17	151.8	28.6
12.4	2.12	149.1	28.2

Table XX. Properties of Synthetic Molding Sand No. 3.

Although the permeability of the synthetic base material No. 2 was somewhat lower than that of the natural base material the permeability of the different synthetic sands agree very closely with that of the natural molding sand. The fact that the permeability of the synthetic sands is more nearly constant with different moisture contents indicates a desirable property for foundry use.

These experiments, although not complete, clearly indicate the importance of adsorbed ferric hydroxide on the properties of natural molding sand, and show that it is possible to duplicate the properties of a natural bonded molding sand from entirely synthetic artificial bonding material.

THE EFFECT OF HEATING

Still further proof of the duplication of the natural sand properties by synthetic means is afforded by investigating the effect of heating on the bond strength and permeability of the natural and synthetic sands.

The behavior of molding sands, when heated, has been studied by a number of investigators and has led to the adoption of a tentative heating test to indicate the durability of different sands. This consists in heating the sand at a temperature of 600° F. for two hours, to determine the relative loss in bond strength due to this heating. The choice of 600° F. in this connection is interesting, since Von Weiman and Higward[50] have shown that *goethite*, natural crystalline ferric hydrate (Fe_2O_3 H_2O), loses most of its water when treated at 608° F. (320° C.) However, hydrated iron oxide[51] [52] appears to be the only metallic hydroxide that will adsorb water and regain its initial surface condition after being dried or heated to this temperature.

[50]Colloid Chemistry, Jerome Alexander, Vol. 1, p. 653, Chem. Cat. Co., New York, 1926.

[51]Paneta and Vorwerk, Zeit. phys. chem. 101, p. 445 (1922).

[52]Hahn and Muller, Zeit. f. Electrochem. 29, p. 189 (1923).
Halm, Naturwissenschaften 12, p. 1140, (1924).
Halm, Liebig. Annalen 440, p. 121. (1924).

For the purpose of indicating the relative durability of the synthetic and natural molding sands, the samples were heated at 600° F. for three hours, then moistened and tested for bond and permeability. This treatment is more severe than that recommended for the durability test in that heating was continued for three hours instead of two.

The heating of the sand was done in an ordinary Fries thermostatic oven provided with a large capacity heating coil and a heavy thermo-regulator.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.6	1.545	108.6	35.9
6.46	1.760	127.2	37.8
8.11	1.975	138.8	33.1
9.82	2.013	141.6	32.4
12.32	1.99	140.0	30.1

Table XXI. Properties for Natural Albany Molding Sand Heated to 600° F. for Three Hours.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.92	1.57	110.8	33.2
5.95	1.84	129.8	33.0
8.2	2.01	141.9	34.1
9.9	2.02	142.6	31.3
12.1	2.08	146.5	30.6

Table XXII. Properties of Synthetic Molding Sand No. 1 (Natural Base Material plus Synthetic Bond No. 1, Heated.)

The dry samples of sand were spread in layers ½" thick in a black iron baking pan, placed in the oven, and allowed to a temperature of 600° F. at which temperature the material was held for three hours.

Te properties of the heated natural and synthetic sands are given in Tables XXI, XXII, XXIII, XXIV, and Figures 16 and 17.

The strength of the natural and synthetic molding sands are decreased to about the same extent by heating to 600° F. for three hours. The permeability of the natural and synthetic sands are increased to about the same degree by the heat treatment. This affords further evidence that the natural molding sand has been substantially duplicated by synthetic means.

The data presented indicate that the bond, permeability, and durability of high grade natural molding sand such as is known as "Albany Sand" can be substantially duplicated and restored by synthetic means using adsorbed ferric hydrogel as an agent to prepare the surfaces of the sand and clay, and that ferric hydrogel is an important factor in the bond of high grade natural bonded molding sands.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.95	1.62	114.2	32.4
7.40	2.03	142.8	32.9
9.65	2.068	144.3	29.8
12.16	2.08	144.3	29.6

Table XXIII. Properties of Synthetic Molding Sand No. 2 (Synthetic Base Material No. 2 plus Synthetic Bond Material No. 1) Heated.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.02	1.51	106.4	34.2
8.16	2.01	141.4	34.8
10.31	1.99	140.0	30.9
12.63	1.97	139.0	28.9

Table XXIV. Properties of Synthetic Molding Sand No. 3 (Synthetic Base Material No. 2 plus Synthetic Bond Material No. 2), Heated.

The fact that synthetic molding sands No. 1 and No. 2 show slightly higher strength and lower permeability than the natural sand and synthetic sand No. 3, is, no doubt, due to the fact that in preparing the bond material used in synthetic sands No. 1 and No. 2 crushed silica was used instead of the more rounded grains occurring in the natural sand or in the synthetic material used in preparing synthetic sand No. 3.

BOND IN MOLDING SAND

Bond in natural molding sand is due to adsorbed colloidal material on the surface of the sand grain which forms a jell upon the addition of water which, reinforced by fine particles such as silt and clay, serves to bind the particles of the sand together. Although it may not be necessary that the colloid be ferric hydroxide as any other similar material might serve equally well, it appears that ferric hydroxide is the most satisfactory material for this purpose as it is a reversible colloid at all temperatures as high as 600° F., and is an important ingredient in natural molding sand.

MOLDING SAND "TO ORDER" FROM UNBONDED MATERIALS

The successful attempt to duplicate the properties of a natural sand in the manner described indicates that artificial or synthetic molding sands possessing all the desirable qualities of natural molding sand may be prepared commercially from pure silica or unbonded sand, particularly when freight rates of $3.00 or more per ton must be added to the original cost of high grade natural molding sand.

Silica

For scientific reasons, at least, the preparation of bonded systems from pure silica, kaolin, and ferric hydrosol should be investigated as well as the synthetic molding sands described.

In the synthesis of the molding sand previously described the base sand furnished the starting point. In this case ground, fused silica was used. This base silica was tested for bond and permeability by the methods described and with the results given in Table XV, and plotted in Figure 20 and Figure 21.

Percentage H_2O	Breaking Strength in Compression.		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.69	1.541	108.6	32
4.00			
4.32	1.587	110.9	
5.01	1.644	115.6	
5.5	1.733	121.1	
6.48	1.806	126.2	
7.00			32.4
7.17	1.81	127.2	
8.0	1.902	132.9	
9.0			32.4
10.06	2.098	146.5	
10.1	1.975	138.0	
10.82	1.991	140.0	
11.			31.1
12.0	1.965	135.9	
12.9	1.885	131.7	

Table XXV. Properties of Crushed Fused Silica Used as Base for Bonded Systems.

The synthesis of the *silica base material* was accomplished by the same method (used in the preparation of the base material of the synthetic molding sand) using the base silica and ferric hydrosol. One percent of ferric oxide as hydrosol was added to the silica. The properties of the silica base material are given in Table XXVI, and Figures 20 and 21.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.66	1.647	115.7	30.8
4.00			
5.74	1.99	140.0	31.4
7.00			
8.32	2.17	152.5	31.7
9.00			
10.35	2.27	159.5	30.8
11.00			
11.05	2.28	161.0	

Table XXVI. Properties of Silica Base Material. (Base Silica plus 1% Hydrated Iron Oxide.)

Mixture of Silica and Kaolin. A mixture of 85% percent ground fused silica and 15 percent kaolin was prepared without the use of ferric hydrosol. This mixture possessed properties as given in Table XXVII, and plotted as "silica and kaolin" in Figures 20 and 21.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.00			9.9
4.53	4.90	344.3	
6.66	4.42	322.0	
7.00			8.8
9.00			8.4
9.33	4.24	299.3	
11.00			7.6
11.76	3.99	280.8	
14.14	3.518	245.0	

Table XXVII. Properties of Silica-Kaolin Mixture.

Silica Base Material Plus 15% Kaolin. The combination of the silica base-material and 15 percent kaolin was brought about in the manner described and tested with the results given in Table XXVIII, and plotted in Figures 20 and 21.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.00			4.8
4.28	5.71	401.5	
7.00			7.2
7.05	5.895	414.5	
8.96	5.14	361.5	
9.90			9.9
11.00			11.4
12.46	4.11	289.0	

Table XXVIII. Properties of Silica Base Material plus 15% Kaolin.

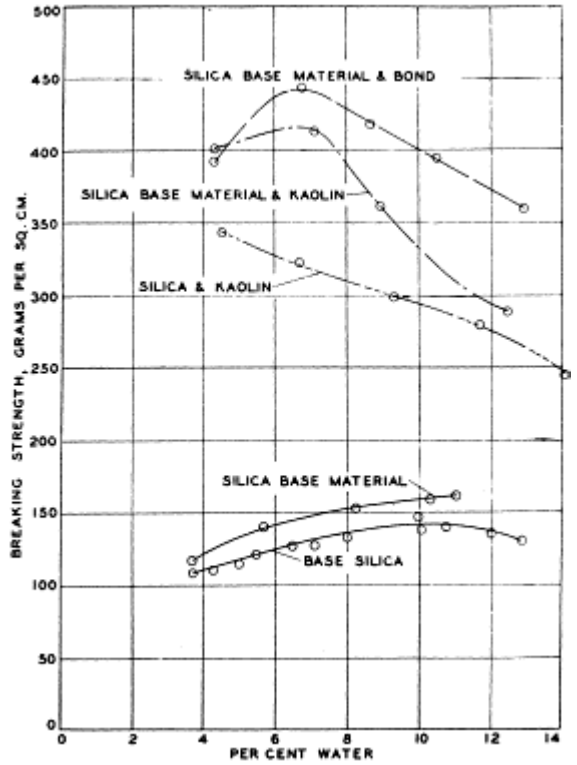

Figure 20. Compressive strength of materials used in synthesis of bonded molding sand.

Silica Base Material plus 15% "Bond Material" (Kaolin with 0.44% Iron Oxide as Hydrated Iron Oxide). To the silica-base-material 15 percent of kaolin containing 0.44 percent of iron oxide was added with the results given in Table XXIX and plotted in Figures 20 and 21.

Results. These results are a further evidence of the importance of adsorbed ferric hydrosol on the bond and permeability of silica-clay mixtures. The addition of one percent of ferric hydrosol to silica increases the bond strength almost ten percent with practically no effect on the permeability. The addition of 15 percent of kaolin to silica approximately doubles the bond strength and decreases the permeability to less than one-third of its previous value. If the silica has been previously treated with one percent of ferric oxide as hydrosol the addition of 15 percent kaolin to silica almost trebles the maximum compressive strength of the silica, and the permeability is higher than that of the mixture of silica and kaolin without the presence of adsorbed ferric hydrosol. If the kaolin also contains some adsorbed ferric oxide as well as the silica particles the compressive strength is still further increased and the permeability is also greatly improved.

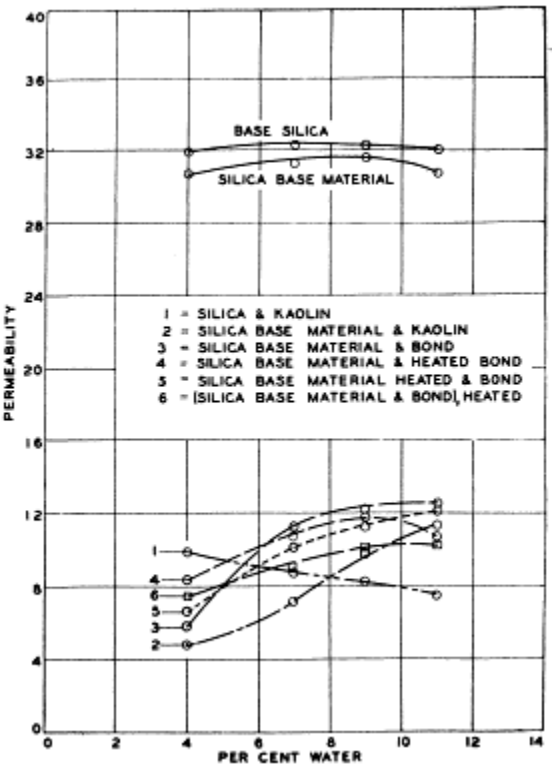

Figure 21. Permeability of synthetic materials.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.00			5.8
4.23	5.58	392.2	
6.72	6.32	444.0	
7.00			11.3
8.65	5.96	418.2	
9.00			12.3
10.50	5.62	395.0	
11.00			12.6
12.93	5.115	360.0	

Table XXIX. Properties of Silica Base Material Plus 15% Kaolin Containing 0.44% Iron Oxide as Hydrated Iron Oxide.

The bond and permeability of synthetic or artificially bonded sands prepared from sand and clay without making proper allowance for adsorbed ferric hydroxide are much lower than if a small amount of ferric hydrosol is adsorbed on the sand and clay particles. This fact has been recognized at least qualitatively for some time, as indicated by the many references to the importance of ferric hydroxide in the bond of molding sand, but the results reported here are believed to be the first results obtained showing quantitatively the importance of adsorbed ferric hydroxide to the bond and permeability of molding sand.

Sand

A clean beach sand from the Michigan City district was mixed, treated with iron hydrosol and mixed with 15 percent kaolin containing 0.44 percent hydrated iron oxide as described. This synthetic material was tested

for bond and permeability with the results given in Table XXX and plotted in Figure 22.

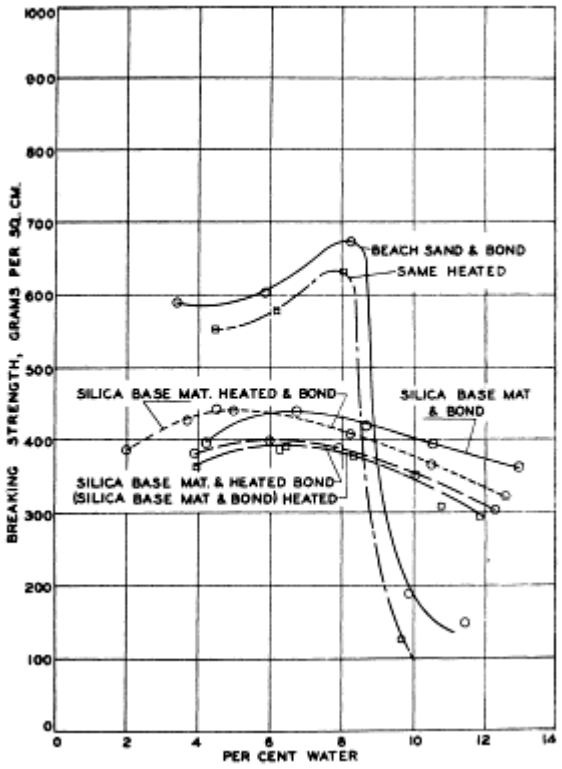

Figure 22. The effect of heat on compressive strength of various synthetic materials.

Per cent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.41	8.44	592	
5.90	8.6	604	
8.32	9.63	676	45
9.89	2.69	189	
11.44	2.12	149	

Table XXX. Properties of Michigan City Sand Base Material Plus 15% Kaolin Containing 0.44% Hydrated Iron Oxide.

The same sample was then dried, heated at 600° F. for three hours, and then tested for bond and permeability with the results given in Table XXXI and plotted in Figure 22. Its permeability was increased from 45 at 8.3 percent water to 55 at 8.1 percent water by this heating.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
4.5	7.92	556	
6.2	8.38	581	
8.1	9.02	633	55
9.7	1.79	125.5	
12.			

Table XXXI. Properties of Beach Sand (Michigan City) Base Material plus 15% Kaolin Containing 0.44% Hydrated Iron Oxide Heated to 600° F. for Three Hours.

GREEN BOND

The permeability of the silica-kaolin mixtures decreases with successive additions of water whereas the permeability of the silica-kaolin-iron oxide combinations shows an increase with water content (Figure 21). This may be taken as an indication that adsorbed hydrated iron oxide on the particles of silica is present as a gel which takes up water and swells, thereby forming larger particles tending to become spherical or causing the separate grains rains to agglomerate, in either case increasing the permeability of the mass.

Simple mixtures of clay and sand are not satisfactory for molding sands unless the clay is so distributed over the sand grains as to exert a cementing or bonding action between the sand grains. The addition of clay to sand or silica increases the bond as indicated in Figure 20 but the full bonding power of sand is not developed unless there be some adsorbed colloidal gel to aid in bonding the sand and clay.

Preliminary experiments on sands bonded entirely by ferric hydro-gel indicate that such material may make excellent cores or dry molds although lacking in strength when wet. It possesses extremely high dry strength and water in excess causes spontaneous disintegration with easy shaking out.

DRY BOND

As sands in the foundry are subjected to temperatures considerably higher than 100 to 110° C. (212° to 230° F.) when metals are cast into sand molds, dry strength may be just as important as moist or green bond and tests on sands heated to reasonably high temperatures may give valuable information. Cores bonded with linseed or tung oil lose their dry strength when heated to temperatures of 230° to 250° C. (450° to 480° F.). The sand mold in serving as a container for molten metals abstracts heat from the molten metal at least until the latter is solidified next to the sand surface. After the casting has solidified where it comes into contact with the sand, the casting may in turn serve as a container for the sand which has insufficient strength to hold itself together. Hansen[53] made a preliminary investigation on a number of sands prepared by bonding Cedarville sand with five percent of clay obtained from different sources heated to 130°, 180°, 300°, and 600° C. In all cases the dry strength decreased regularly as the temperature to which the' sand was heated was increased. As the decrease is rather regular Hansel concludes that the determination of the strength of clay bonded sands heated to 100° to 120° C. determines also the order of the strength at such temperatures that concern us in giving form to castings.

Adequate dry strength may be obtained by molding heavily clay-bonded sands at relatively low moisture content, or by molding moderately low clay-content sands at relatively high moisture. The low-clay high-moisture sands are decidedly to be preferred as being the more fool-proof. Molds may be lost in making because such sands have little green strength, but it is better to lose the mold than to make the mold and lose the casting.

[53]Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 57.

Relation Between Green Bond Strength and Dry Strength

After carefully testing the strength of the green and dry strength of a number of sands, Hansen54 finds that the dry strength approaches zero as the green strength approaches its maximum on a decreasing moisture scale. He calls attention to the fact that it is not likely to be a mere coincidence, that when experienced foundrymen were asked to temper the same sand, they did temper by feel to a point reasonably close to the saturation limit containing considerably more moisture than that corresponding to the point of maximum green strength. Clearly, the direct determinations of the dry strength is important and determinations of the green bond strength may not be substituted for dry strength.

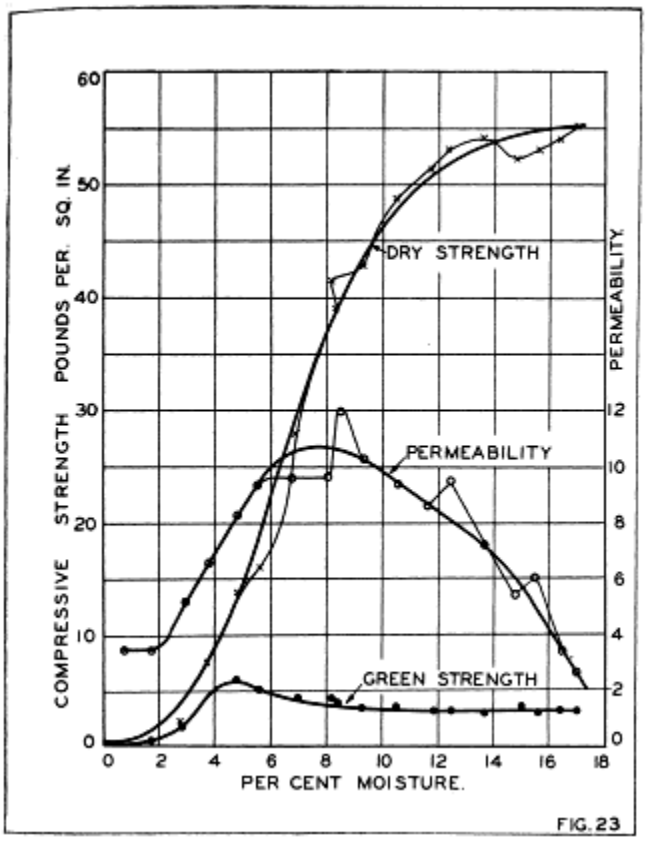

Figure 23. Effect of water content (moisture) on dry strength, permeability, and green strength.

Figure 23 shows the effect of moisture on the green strength, dry strength and permeability of sample 17, a commercial Michigan molding sand. The actual points are connected by light lines to indicate the actual changes with moisture. The heavier smooth lines are drawn in the conventional manner.

[54]Transactions of the American Foundrymen's Association, Vol. XXXII, Part II, page 57.

DURABILITY OF BOND

Methods of Test

The effect of heat upon the colloid content as indicated by the dye adsorption test was investigated by Harrington, McCombe and Hosmer.[55] Three different sands were heated to temperatures varying from 212° to 1900° F. and subjected to the dye-adsorption test. The results showed a steady decrease in the dye-adsorption value, as the sands were heated to about 1000° F. Further heating to about 1500° to 1600° F. caused only a very slight further decrease in the dye-adsorption value. But heating to higher temperatures above 1600° or 1700° F. caused a further rapid decrease in the dye-adsorption value.

From these tests, the conclusion was reached that, generally, the percent lost in dye-adsorption value on heating a sand to 1700° F. indicates approximately the relative destruction of the bond in actual foundry use.

As has been pointed out, the dye-adsorption test may not be a direct indication of the bond strength or even of the colloidal content of the sand, as it depends upon an equilibrium between the dye adsorbed on the surface of the sand particles with the dye in solution. However, the results from this investigation clearly indicate that heating has a marked influence on the condition of the surfaces of the grain and may cause agglomeration of the sand particles, or a destruction of the colloid, or both.

[55]Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 47.

Heat Test for Durability. About the same time H. W. Dietert[56] recommended heating the sand to 600° F. for a period of two hours and deter mining the percent loss in bond strength, as an indication of the practical life of a molding sand. Dietert, however, refers to an actual strength test instead of the dye-adsorption as an indication of the bond strength.

Figure 24* shows the effect of heating a Zanesville sand from room temperature to 1900° F. as reported by Dietert. In this plot strength is determined by a compression test, the percentage bond ("clay content") by a vibratory test[57] which is essentially a method of hydraulic classification of the particles in the sand, and the permeability determination by the Standard A.F.A. method.

The notations made on the chart are interesting in indicating that Dietert believes the most important change occurring up to 200° is drying of the sand, and at about 400° to 500° F. oxidation of the organic substance which is accompanied by a rapid decrease in the bond strength, 1 at about 700° to 800° F. the dehydration of the clay substance, accompanied by a rapid decrease in the fine particles, reported as bond determined in the Smith vibratory test, and by a more rapid increase permeability.

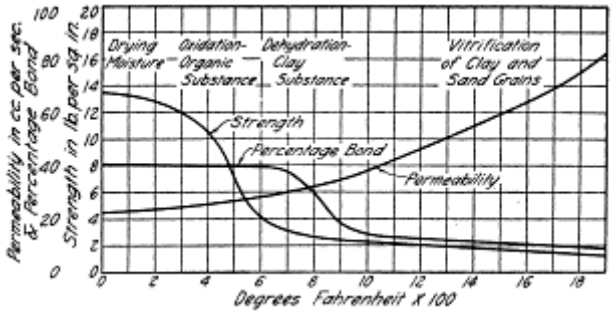

Figure 24. Effect of heat on Zanesville sand.

[56]Transactions of the American Foundrymen's Assocation, Vol. 32, Part II, page 24.

*Trans. A. F. A. Vol. 32, Part II, page 35.

[57]Smith—Transactions of the American Foundrymen's Association, Vol. 31, page 623.

Rehydratability Test. It is important to distinguish between the quality of the bond in the sand, and the amount of bond in the sand, as well as other factors determining the life of the sand, dependent upon conditions of use. It is known[58] that many colloids, particularly silica silicates, humus, colloidal hydroxides of iron, alumina, and manganese, are found in soils. Nevin regards silica, hydrated iron, and alumina as the most important in molding sand.

On the assumption that these colloids are destroyed to a greater or lesser extent on heating the sand, a rehydratability test has been proposed[59] to measure the ability of these colloids to readsorb water after heat.

The method of conducting the test is to take approximately twenty-five grams of sand, and dry it to a constant weight at 105° C., which usually requires about four hours. The sample is then cooled in a dessicator and weighed accurately on an analytical balance. The sample is then heated to the desired temperature for the period of about one hour, after which it is again cooled in the dessicator, and quickly and accurately weighed. The loss in weight is considered to be the *dehydration* of the molding sand at that temperature, and is expressed as a percentage of the original weight of the sample. Sufficient water is then added to the sample so that it is entirely covered. After soaking for twelve hours, the

sample is then dried by heating to 105° C. to constant weight. This usually requires about eight hours. It is then cooled in a dessicator and weighed. The increase in weight, due to the adsorption of water of rehydration expressed as a percentage of the original weight is called the rehydration factor. As the sand tends to adsorb moisture from the air all weighing must be conducted rapidly.

In making the actual laboratory casting test, 4000 grams of each sample sand were tempered with the proper amount of water to develop the highest strength and rammed in a straight sided tin flask, 5 x 5 x 7 inches around a wooden pattern. The pattern was then pulled and a gray iron casting poured which was allowed to become cold before removal. The casting used was a square cross-section of two and one quarter inches about three inches long. These tests were continued without the addition of new sand, until ten heats had been cast in each sand.

A comparison of the results obtained in testing these sands, after each heat, indicates that the life of the sand is dependent upon the amount of bond originally present and upon the quality of the bond.

The same sands were carefully heated to 600° F. for two hours in a large oil-fired muffle kiln. To eliminate so far as possible non-uniform heating the sand was heated slowly and spread out in a thin layer. The bond strength of these heated samples was determined by means of the Standard A.F.A. Cohesiveness test. The percent lost in bond strength determined in this way, was found to be a rather misleading criterion of the life of the molding sand as determined in the laboratory casting tests described above.

On the assumption that change in the colloid conditions are responsible for the decrease in bond as the sand is subject to actual use in making castings, and regarding the dye-adsorption test as an unsatisfactory indicator of the colloidal nature of the sand, Nevin regards the difference in the percent of dehydration determined at 300° and at 600° C. as an indication of the durability or life of the sand, the less desirable sands showing a smaller difference as most of the dehydration occurs at lower temperatures. He then determines the rehydration at 600° C. and uses this figure as a rehydration factor as an indication of the durability of the sand under adverse foundry conditions.

"Since therefore both the dehydration and the rehydration figures are considered as reflecting the same factors—amount and quality of the bond—and since rehydration will counteract to some extent the effect of dehydration, it seemed logical to multiply these related figures so as to secure a life figure. This is done in Table XXXII and the result multiplied by 1000 to give whole numbers."

[58]Robinson and Holmes—Chemical composition of Soil Colloids, U. S. Department of Agriculture, Bulletin 1311, 1924.

[59]C. M. Nevin, Transactions of the American Foundrymen's Association, 33, page 763.

Comparison of Methods. The agreement in relative rating of the life of the sand as determined by the laboratory casting method (columns 12 and 13, Table XXXII) and the hydration life factor (column 14) is much better than between the laboratory casting method and the percent lost in bond strength on heating the sand at 600° for 2 hours (column 16), because the life of the sand depends on the quantity of bond as well as its quality.

Heating the sand at 600° F. for two hours and determining the percent lost in bond does not consider the amount of bond present, but simply its quality. A figure indicating the life of the molding sand taking into account both the quantity of the bond and the quality of

the bond obtained by using simply the residual bond strength after heating for 2 hours at 600° F. The relative rating on this basis is as good as obtained by the more complicated rehydration life factor.

1	2	3	4	5	6	7	8	9
	Transverse or Cohesiveness Strength							
Sample	10 Heats	5 Heats	Green	2 Hrs. at 600° F.	Percent Loss	Percent Dehydration 300° C.	600° C.	Diff.
1	154	242	390	305	21.8	1.10	2.81	1.71
12	137	177	200	205	0.0	1.01	2.82	1.91
18	130	181	202	212	0.0	.56	2.03	1.47
17	115	141	160	155	3.2	.35	1.30	.95
11	100	167	260	195	25.0	.77	2.04	1.27
13	100	150	196	156	20.4	.73	1.53	.80
7	100	178	308	200	35.1	.72	1.90	1.18
2	100	152	298	208	30.2	.55	1.44	.89
20	100	127	167	137	18.0	.71	1.36	.65
16	100	142	161	140	13.0	.94	1.92	.98
19	100	118	145	119	17.9	.41	1.11	.70
4	100	118	154	155	0.0	.23	.72	.49

	10	11	12	13	14	15	16	17
			Order of Rating Based on					
Sample	Rehydration at 600° c.	Rehydration Life Factor	10 Heats	5 Heats	Rehydration Life Factor	Strength 2 Hrs. at 600° F.	Percent Loss	Strength 2 Hrs. at 600 x Percent Residual Strength
1	.43	735	1	1	1	1	9	1
12	.18	326	2	4	4	4	1	4
18	.34	500	3	2	2	2	1	3
17	.15	142	4	9	9	8	4	7
11	.20	254	5	5	5	6	10	6
13	.22	176	6	7	8	7	8	7
7	.29	342	7	3	3	5	12	5
2	.22	196	8	6	7	3	11	2
20	.20	130	9	10	10	11	7	10
16	.22	215	10	8	6	10	5	10
19	.17	120	11	11	11	12	6	12
4	.16	78	12	11	12	9	1	9

Ref. Nevin, Trans. A. F. A. XXXIV, p. 763.

Table XXXII. Comparison of Laboratory Casting Rehydrability and Heating Tests for Durability.

A comparison of the data of Table XXXII (columns 12 to 15 and 17) that the bond strength remaining after heating a sand to 600° F. for two hours, and the dehydration life factor based on tests at 300° C. and 600° C. as proposed by Nevin classify the sands in approximately the same order so far as life of the sand is concerned. Since Nevin considered the sand *burned out* as soon as their bond strength, as determined by the transverse or cohesiveness test, was decreased to 100, it seems much more logical to compare the heating tests at 600° F. in the manner which half been done in column 15 in the above table rather than to use the percent decrease in bond, column 16, as the indication of the life of the sand.

If the life of a molding sand is considered as composed of two factors the quantity of the bond material and the durability of the bond material or its quality, it seems much better that these two properties of these two factors should be determined separately and then combined, if desirable, rather than to lump the two properties together as has been done in the hydration life factor.

The laboratory casting test indicates that the hydration life factor and heating to 600° F. for two hours, more closely approximate the results obtained after five or six heats than those obtained after 10 heats. Neither the hydration life factor nor the heating test can be regarded as exact indicators of the life of the molding sands, but practical considerations would indicate that the addition of new sands or other bond material would be required after the molding sand had depreciated to about the extent indicated after five or six heats, and that it would be impractical to produce satisfactory castings before the sands had depreciated to the extent indicated by ten heats in the above table. For these reasons, the heating test as an indication of the quality, or life, of the bond material in the sand, is considered satisfactory and has been used in this bulletin because of its apparent greater simplicity and significance.

The Causes of Failure Due to Heating

Various factors have been used to explain the decrease in the bond of molding sands after continued use. Nevin and Harrington believe this is due to a destruction of the colloid, or a partial dehydration of the colloid matter in the sand, but Dietert seems to indicate that it is due to dehydration of the clay substance. Whether or not clay substance and colloid matter are used synonymously by these different writers is not clear. Having shown the importance of adsorbed colloidal ferric hydroxide in the bond structure of high grade molding sands in the previous section, it seemed that valuable information might be obtained if tests were conducted to show what effect heating to 600° F. had upon the clay bond and the ferric hydrogel bond constitutents.

Experimental Data. For this purpose the synthetic bonded material made from pure silica, kaolin, and ferric hydrogel was used. The choice of pure materials was made to eliminate so far as possible the confusing influence of unknown impurities. In these tests the silica base material and the bond materials were heated separately, then mixed with unheated bond and base material respectively. These mixtures were then compared with the unheated bonded system, prepared by mixing unheated base material and bond material and with the bonded system mixed before heating.

The kaolin bond material containing the adsorbed hydrated iron oxide was heated at 600° F. for three hours, cooled to room temperature, and mixed with the silica base material in the manner previously described. This mixture was tested for bond and permeability with the results given in Table XXXIII and plotted in Figures 21 (curve 4) and 22.

The silica base material was heated at 600° F. for three hours, cooled to room temperature, and combined with the unheated kaolin bond material in the manner described. This mixture was tested for bond and permeability with the results given in Table XXXIV and plotted in Figures 21 (curve 5) and 22.

The silica Base-Material was mixed with the bond material (Kaolin with 0.44% iron oxide as hydrated iron oxide) and the mixture heated at 600° F. for three hours. This heated mixture was tested for bond and permeability with the results given in Table XXXV and plotted in Figures 21 (curve 6) and 22.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.9	5.455	383.5	8.4
4.0			
6.0	5.685	400.0	10.8
7.0			
7.95	5.528	390.5	11.85
9.0			
10.1	5.02	352.0	10.8
11.0			
12.3	4.32	304.0	

Table XXXIII. Properties of the (Silica Base-Material) Plus (Kaolin Containing 0.44% Iron Oxide as Hydrated Iron Oxide, Heated to 600° F. for Three Hours.)

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
2.0	5.515	389	6.7
3.7	6.116	430	
4.0			
4.55	6.34	446	10.2
5.0	6.274	441	
7.0			
8.25	5.76	409.5	11.3
9.0			
10.55	5.21	366.2	12.1
11.0			
12.6	4.60	322.9	

Table XXXIV. Properties of Silica Base Material Heated at 600° F. for Three Hours Plus 15% Kaolin Containing 0.44% Iron Oxide as Hydrated Iron Oxide.

Percent H_2O	Breaking Strength in Compression		Permeability
	Lbs./Sq. In.	Gms./Sq. In.	
3.96	5.204	366	7.5
4.00			
6.28	5.51	388	9.1
6.42	5.60	394	
7.00			
8.4	5.40	380	10.0
9.0			
10.8	4.405	310	10.4
11.0			
11.86	4.222	295	

Table XXXV. Properties of Silica Base Material Plus 15% Kaolin Containing 0.44% Hydrated from Oxide, Heated at 600° F. for Three Hours after Mixing.

Discussion. Heating the silica base before mixing it with the bond material has no noticeable effect on the maximum strength of the bonded system. This indicates that the loss in bond on heating, at least to 600° F. for three hours, is not due to any change in the ferric hydrogel adsorbed on the silica. This fact is a further verification of that reported! by Halm[60] that hydrated ferric oxide is reversibly pektized on heating to this temperature. Heating the silica base does seem to shift the point of maximum strength toward drier mixtures from about 7 to 5 percent water content. This may be due to the heated gel being more easily wetted and therefore weaker at the higher water contents.

On the other hand, heating the bond material before mixing with the silica base material causes the mixture to lose practically all of the strength lost on heating the bonded mixture. This clearly indicates that the loss in bond on heating is due entirely to changes in the clay bond g distinct from the sand or colloidal ferric hydrogel. Although the mineral kaolinite ($Al_2O_3.2\ SiO_2.2H_2O$) has shown no evidence of decomposition at temperatures as low as 600° F.[61] other hydrous aluminum silicates present in kaolin such as *halloysite* and *allophane*[62] show evidences of dehydration at temperatures as low as 300° F. (150° C.). Bigot reports that clays are partially irreversibly pektized at 350° to 600° C.

It seems evident that the loss in strength on heating is due to changes in the clay, either by decomposition of the crystal structure or by changes in surface conditions and not due to changes in the sand particles or in the ferric hydrogel adsorbed thereon.

Samples 284 and 287 from Houghton County contain relatively large quantities of iron oxide and were tested for durability with the results indicated in Figure 25, showing that these natural sands bonded at least in part by iron oxide have a higher durability as is indicated by the work on synthetic mixtures.

Whether or not heating may destroy other colloids than ferric hydroxide contained in the clay has not been determined as the pure kaolin used in these tests had been carefully washed and was practically free from adsorbed salts. This seems to verify the statement made by Dietert that heating the sand to temperatures of 600° F. causes dehydration or decomposition of the clay material in the sand bond.

The changes occurring in molding sand in actual foundry practice may not be the same as those occurring in the sand when heated to 600° F. The differences in treatment are, of course, pronounced. In foundry practice, a small part of the sand adjacent to the metal casting is heated to a relatively high temperature, considerably above 600° F., while in the heating test above, the whole sample of sand is more uniformly heated to a relatively low temperature of 600° F. The fact that comparative tests based upon actual casting and heat treatment yield generally similar results indicates that the changes brought about in actual foundry practice can be fairly well approximated by the heat treatment test.

Figure 24 by Dietert and similar tests on Michigan sands clearly indicates that most of the strength lost on heating occurs when the sand is heated to 600° F. and that it is not necessary to heat the sand to higher temperatures. Nevin's rehydratability test based on heating the sand to 572° F. (300° C.) and 1112° F. (600° C.) gives similar results (Table XXXII). These facts considered with the results of the tests just described which clearly indicate the ferric hydroxide bond is not destroyed on heating to 600° F. but that all loss in bond strength is due to changes in the kaolin or hydrated aluminum silicates lead to the conclusion that the loss in bond strength is due to changes in the clay bond rather than in the sand grains or ferric oxide bond.

L. B. Thomas[63] calls attention to the fact, that although two molding sands having similar characteristics will stand up fairly well under actual casting tests, when using a ratio of three parts of a sand to one part of iron by weight, in those cases where the casting weighs more than the sand in the mold, considerable difference will be observed in the durability of the sand. The reasons for these differences are not given. It may be

due to the fact that one sand contains more moisture than another and is therefore, protected from the higher temperatures, as vaporization of the moisture will adsorb a large part of the heat conducted into the sand from the molten metal.

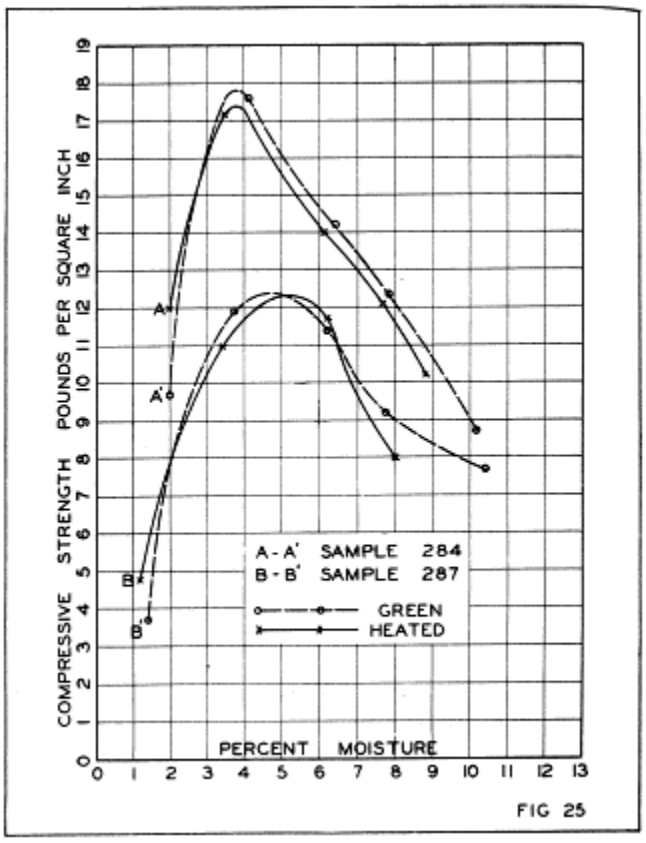

Figure 25. Effect of heating to 600° F. on compressive strength and permeability of two Michigan iron bonded sands.

Dry Strength. The above discussion on durability of bond has been limited to green bond, that is the bond of the sand while moist. In actual foundry use the sand adjacent to the casting is always dry, even when the casting is made in green sand. For this reason, the dry strength of molding sand is of considerable importance. The bond that one feels with the hand is the green strength. This is important to avoid difficulty with the sand during molding and on handling. But every green sand mold is a skin dried mold before it is completely poured. The sand, therefore, successfully serves its purpose due to its dry strength.

Dietert[64] finds that the dry bond strength changes very slowly compared to the green strength. A. A. Grubb[65] points out the importance of the dry strength of the sand. In testing two different sands for durability, Grubb shows that the dry strength decreases eighteen percent and thirty-five percent, although the green bond had not been decreased at all by heating the sand to 600° F. for two hours. These considerations certainly indicate the importance of dry sand strength determinations which should always be made in any attempt to accurately evaluate a molding sand.

[60]Hahn-Zeit. F. Elecktrochemie 29 (1923) p. 189.
Naturviss. 12 (1924) p. 1140.
Lubig Annalen 440 (1924) p. 121.

[61]S. Satch—J. Am. Cer. Soc. IV, p. 182 (1921).

[62]Le Chatelier, Compt. Randu. 104, p. 1443 (1887).
Ding. Polyt.J. 265, p. 94 (1887).
A. Bigot—Compt. rendu. 176, p. 91 (1923).

[63]American Foundrymen's Association, Vol. 34, p. 355.

[64]Transactions of the American Foundrymen's Association, Vol. XXXIV, p. 248.

[65]Instruments, January 1928.

REFRACTORINESS

DEFINITION

Refractoriness is resistance to heat and may be defined as the quality of being difficultly fusible. It must not be confused with durability which concerns itself entirely with the ability of the clay and colloid matter of the sand to readsorb water and bond the sand again in the same manner as before the sand has been used or heated. Refractoriness is measured by determining the temperature at which the sand begins to melt or fuse.

IMPORTANCE

If the sand will not withstand the temperature at which the metal is poured into it without melting, the finer particles of the sand, such as the silt and clay, will actually fuse and become included in the surface of the casting. Even if the sand grains are sufficiently refractory some particular mineral in the sand, may possess a low fusion point and form pits in the surface of the casting. The first of these troubles is known as "burning-on", and the latter as "pitting". Both are due largely to the chemical composition of the sand and of the clay substance contained therein.

The effect of the presence of limestone or calcium carbonate in causing pitting has been indicated. If the sand is completely weathered practically all of the calcium carbonate will have been removed. As calcium carbonate is one of the most important fluxing agents found in sands, the color of the sand found in Michigan may be taken as a rough index of its refractoriness, as the deep red sands are leached free from lime an generally the light yellow or buff sands contain lime, either in grains or disseminated throughout the sand.

Because the range of fusion points of sands, from 1350° C. (2462° F.) to 1700° C. (3090° F.) is approximately the same as the casting temperatures of iron and steel, from 1300° C. (2372° F.) to 1670° C. (3038° F.) slight differences in the fusing temperatures of sand are important.

TEST FOR REFRACTORINESS

Although chemical analysis is indicative of the ability of the sand to resist high temperatures a direct physical

test of the fusion point of the sand is far more valuable as many other factors besides the chemical compounds present determines the refractoriness of a sand. Even the interpretation of direct tests of the melting point of sands offers real difficulty, as the sand is used in the foundry under different conditions than ordinarily encountered in furnaces used for determining the melting point.

In foundry practice the sand is in intimate contact with hot molten iron or steel and under reducing conditions, whereas ordinarily in the testing furnaces the atmosphere is maintained oxidizing.

D. W. Trainer[66] prepared a series of specimens by mixing clean silica sand with a glacial clay having a fusion temperature of approximately 1350° C. These samples were prepared in the form of cones and fired in a muffle under oxidizing conditions in the conventional manner for making fusion tests of clays.

The results (Figure 26) show that none of the sand failed until the fusion point of the bonding clay was reached, and that all specimens of sand containing fifty percent or more of clay failed at approximately the same temperature as the pure clay. Similar tests conducted on bars showed that the bars containing the greater percent of clay failed at the lower temperatures.

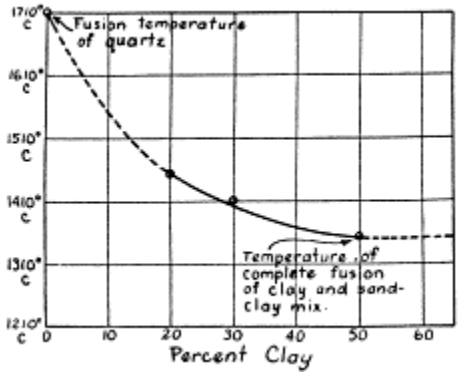

Figure 26. The relation between the fusion temperature of sand-clay mixture and the percent of clay in the mixture.

[66]Transactions of the American Foundrymen's Association, Vol. 34, page 327.

THE EFFECTS OF CLAY AND COLLOIDAL BOND

Although these tests were conducted under oxidizing conditions the results clearly indicate that the refractoriness of the sand is generally limited by the relatively low refractory properties of the clay, and the amount of clay contained in the sand at least up to 50 percent clay.

Trainer calls attention to the fact that in many of the sands tested in his laboratory, it was found that the grains were entirely or partially coated with iron oxide film. He states that this iron oxide adsorbed on the surface of the sand grain may be an important factor in starting the fusion of the quartz, since in such cases, a flux is in very intimate contact with the quartz grains. A. A. Grubb[67] also calls attention to the fact that iron compounds are not as refractory as those of aluminum, but are more plastic, and it is generally believed that high iron sands peel from castings better than high aluminum sands. A consideration of these facts clearly indicates that the refractoriness of a sand as determined under oxidizing conditions or even under reducing in a gas-fired or muffle furnace, is not an accurate indication of the refractoriness of that sand when used in a mold in contact with hot molten metals.

Further contradictory statements of the same kind may be found between these two authors. Trainer[68] states, “Some have thought that the size of the grain may have an influence on the refractoriness of the sand. This in general has been found not true.” Grubb[69], on the other hand, basing his conclusions on general foundry experience, rather than laboratory refractory tests states, “It is a well known fact that fusibility depends on particle size as well as on chemical composition.

If we base our conclusions entirely on laboratory tests, no doubt the statements of Trainer are accurate. But, in actual foundry practice, it seems reasonable to expect that the molten iron will flux more readily with the small particles of sand than with the larger because the fluxing must be complete before the iron solidifies, and the larger particles are known to react more slowly. It would seem just as reasonable to expect that the adsorbed film of ferric oxide on the sand particles would act in much the same way as butter or grease in a frying pan and tend to prevent the sand from adhering to the casting as to expect the small amount of adsorbed film oxide on the sand grains to have more effect on the fusibility of the sand than the relatively large amount of molten iron in contact with the sand mold.

Boswell[70] makes a similar statement in calling attention to the fact that molding sands not containing limonite on the sand grains tend to make dirty and poorer castings that those containing the colloidal iron oxide bond.

[67]The Instruments, January 1928.

[68]Transactions of the American Foundrymen’s Assocation, Vol. 34, page 338.

[69]Instruments, January 1928.

[70]Foundry No. 47, pages 148-150.

THE EFFECT OF TREATMENT ON THE PHYSICAL PROPERTIES OF SAND

It is not the purpose at this place to discuss the various factors involved in reclaiming and improving foundry sand, but simply to indicate how the treatment given a sand sample during its preparation and testing may greatly affect the results of the test, and to summarize briefly the important variables determining the physical properties. A. A. Grubb* calls attention to the necessity of carefully breaking up all aggregates, or dusting the sample after drying to prevent the aggregate lumps remaining intact. "If this is not done, abnormally high

permeability values result; if it is done, the values are apt to be lower than that of the heap in which it will be used."

Figure 27 illustrates the differences in physical properties that may be obtained depending on the manner in which the sand has been handled. A sample having a grain fineness of 70 and 23 percent clay content was mined wet and passed through a No. 4 riddle with the resulting test data shown by the solid lines (A) in Figure 27. The sample was then dried, milled and tested again with the results as indicated by the dotted lines (B). This sand is used without other additions in foundry heaps carrying 11 to 14 percent of moisture and the permeability ranges from 60 to 70.

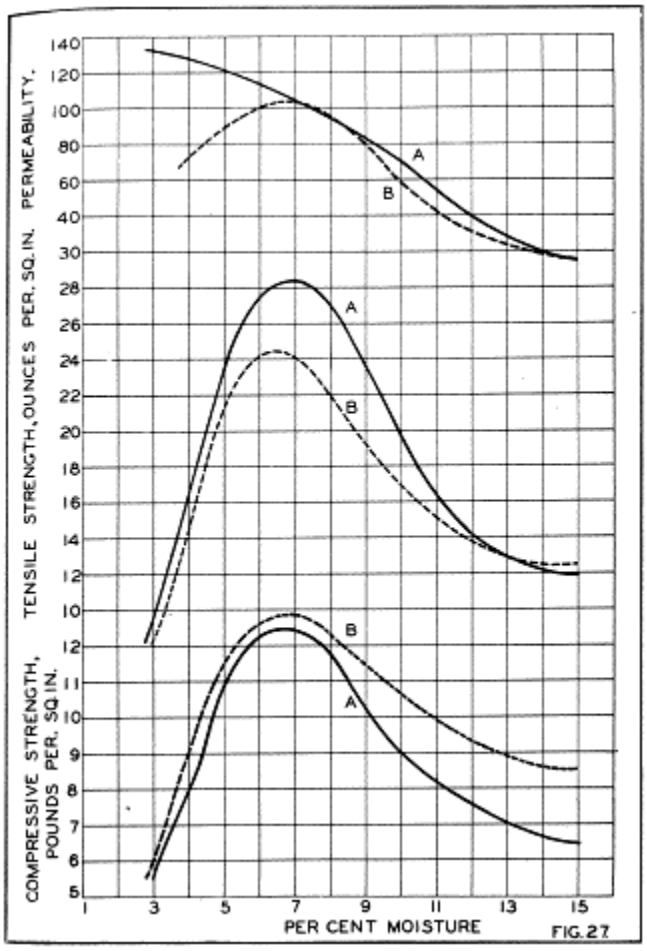

Figure 27. The effect of method of treatment on physical properties. Solid lines (A) represent riddled sample. Dotted lines (B) represent milled sample.

*Instruments, January 1928.

RAMMING

In preparing sand molds the sand is always compacted by ramming. The degree of ramming or the amount of work expended in compacting the sand is a very important variable in the determining of the properties of the sand mold. Perhaps the most thorough investigation into the effect of ramming on the various physical properties of molding sands is that reported by G. A. Hansen.[71] Qualitatively the general statement may be made that increase in the amount of energy expended in ramming a sand decreases the permeability and increases its bond strength, but general quantitative relations cannot now be stated. As pointed out by Hansen it would seem logical to test the permeability on samples of sand that have been heavily rammed and the bond strength on samples that have been lightly rammed, in order to determine the worst possible behavior to be expected of the sand. Unless the ramming and the moisture content used in making these tests are practically the same as those used in preparing the molds, greater differences between the same sand when rammed differently are evident than between different sands.

In Figure 28 the permeability moisture curves are given of sample No. 289 Houghton County as determined from two different sized specimens but rammed with the same total energy. The solid line and points give results as obtained with the Standard A.F.A. permeability apparatus which rams the sand from one end three times by dropping a 14 pound weight two inches on an area of 3.1416 square inches corresponding to a total energy adsorption of 26.7 inch pounds. The broken line and circled points give the results obtained from ramming a sample of one square inch cross-section once by dropping a weight of 7 pounds 1.91 inches, corresponding to an energy adsorption of 13.4 inch pounds each end of the specimen as the mold was designed for top and bottom ramming (Figure 11).

The latter specimen shows a slightly higher permeability indicating that some energy was adsorbed in the mold constructed for top and bottom ramming. But the energy adsorbed by the specimen in ramming seems to be the best criterion of degree of ramming.

[71]Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 57.

TEMPERING OR MOISTURE CONTENT

Nevin[72] investigated the effect of water on the bond strength and permeability of molding sand. Interesting photo-micrographs are shown which clearly indicate that the colloidal matter and clay substance are not uniformly adsorbed on the sand grains unless the proper amount of water is present. As the amount of water is increased the sand particles seem to adsorb the clay and colloidal matter from the spaces between the sand grains, thereby increasing the permeability of the sand and at the same time developing a maximum strength. As the water content is further increased beyond that necessary for the full development of the adsorbed colloid on the particles of sand grains, the bond appears to become diluted with the excess water which also tends to fill up the spaces between the sand grains.

Exactly the same conditions are indicated in the results reported in the investigation into the cause of the bond in molding sand. Water is absolutely necessary for the development of the colloid structure of the mineral oxides in the sand. The adsorption of the colloid on the

sand grains is due to the effect of these colloids on the interfacial tension between the sand particles and water. The water wets the sand particles in much the same way as water wets glass. The colloid particles are then adsorbed in the interface between the sand particles and the water, at the same time adsorbing water themselves and taking on the characteristics of sticky or glue-like properties common to all colloids. The water wets the particles of silt and clay in much the same way as it does the sand grains, thereby serving as a means for uniting or cementing the particles of sand together through the development of the colloid structure which is re-enforced by the particles of silt and clay.

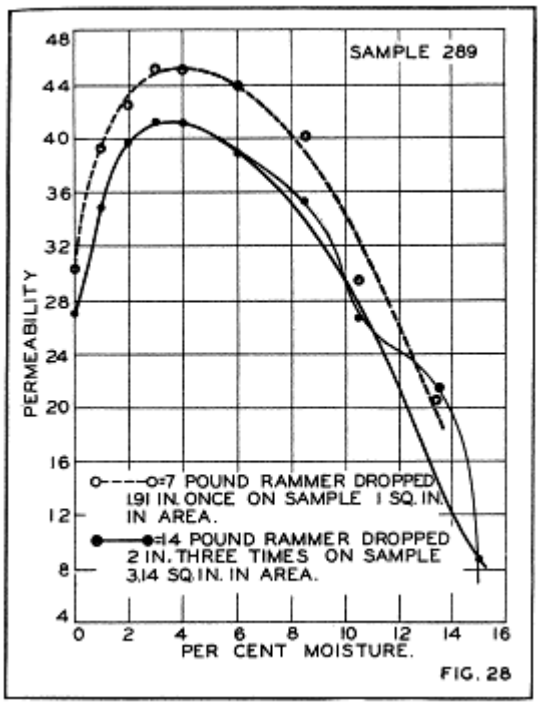

Figure 28. The effect of ramming and moisture on permeability using same relative energy of ramming on different sized specimens.

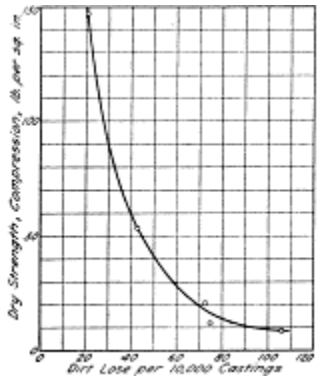

Figure 29. The relation between casting loss and dry strength of molding sand.

In the absence of water the fine particles of silt and clay tend to fill up the spaces between the sand grains. Upon the addition of water and bonding of the sand grains in this manner the fine particles of silt and clay agglomerate with the sand particles tending to form larger particles with larger and smoother interstices. This allows freer passage of the air, developing a greater permeability as well as an increase in the tensile strength and bond of the sand itself. These properties are increased as the water present in the sand is increased up to a certain point, beyond which further addition of water tends to fill up the spaces between the sand grains decreasing the permeability of the sand and diluting or weakening the green bond.

Moisture has an even greater effect on the dry strength than on the green bond strength, as is shown in Figure 29. Experience indicates that the moisture content for maximum dry strength is considerably greater than that for maximum green bond strength. If the sand is then tempered with consideration only for the green bond strength, the dry strength of the sand may be so low as to cause the mold to cut or wash during pouring.

Clearly the purpose of tempering the sand is two-fold. First, to obtain the desirable green properties, such as strength, permeability and texture. Second, to obtain the desired dry strength and dry permeability. The importance of the first has been recognized for some time. Figure 29 from Dietert[73] clearly indicates the importance of having the proper dry strength. Dirty castings seem to be due largely to the cutting and washing of the mold caused by a low dry strength.

[72]Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 168.

[73]Transactions of The American Foundrymen's Association, Vol. 34, page 252 (1926).

Chapter V. SAND CONTROL AND RECLAMATION IN FOUNDRIES

CONTROL OF PHYSICAL PROPERTIES

It is not the purpose to enter into a discussion of sand control in the foundry and the commercial problems involved in the economic utilization and reclamation of mold-sands. But, a discussion of the properties of molding sand would not be complete without a brief discussion of how these physical properties are influenced or improved mechanical treatment of the sand. The effect of moisture and the degree of ramming on the strength and permeability of molding sand have already been indicated.

In actual foundry practice the *degree of ramming* can be maintained fairly constant by a careful check-up of the molding machine or by using the same molders if hand labor is depended upon for this purpose.

MOISTURE CONTENT

Moisture content can be accurately controlled only by a physical test used as a check on the amount of water used to temper the sand. The importance of controlling the water used to temper the sand can not be over

emphasized, because changes in the moisture content cause changes in the bond and the permeability of the sand. If the sand is not properly tempered the green strength and particularly the dry strength of the mold will be affected, causing an increase in the loss of castings. This increased loss is then likely to be blamed on the sand which is then immediately treated by the addition of a large quantity of new sand to bring up the strength. The properties of the heap sand are then greatly changed and the molders have to deal with an entirely different material than that to which they are accustomed. This introduces still further trouble, all of which could be avoided by a careful control of the water used in tempering the sand.

Hansen has investigated in a qualitative way at least, the force required to reduce the moisture content of the sand from that in excess of maximum strength to that slightly less than necessary for maximum strength. This was done by draining the sand on a filter at the end of which treatment it contained 19.1 grams of water per one hundred grains of dry sand. The sand was then centrifuged at the indicated speeds with the results given in Table XXXVI.

R. P. M. of Rotaux Machine	Apparent Weight of One Pound of Water at this Point	Grams of Moisture Retained Per 100 Grams Dry Sand After 10 Minutes Rotation
0 (Filter drained)	1	19.1
210	5.1	16.3
360	14.9	13.5
510	29.8	8.1
1000	116	7.2
2000	464	6.05
2500	724	5.7

Table XXXVI. The Effect of Centrifuging on Moisture Content.

Plotting the values of the second column against those in the third column indicates that for this sand water in excess of 8 percent is not held as tenaciously as that up to slightly less than 8 percent. This indicates that the saturation point so far as colloidal conditions are concerned is about 8 percent.

In many ways the accuracy of the Standard Moisture Test is unnecessary for plant control work, and a more rapid method even of less precision is more satisfactory. Dietert[1] describes a satisfactory method for foundry control, using a sample weighing about 860 grams. The larger sample is more apt to be representative of the heap sand than the small sample used in the oven test, and the short time required—2 to 3 minutes —is of great advantage in foundry control work. This method is based upon the principle that the amount of water displaced by the eight hundred and sixty gram sample when placed in a vessel full of water, is directly proportional to the percent of moisture contained in the sand. A dry sample of sand will displace a small amount of water, a wet sample will displace a larger amount. Of course, such a method would be useless in testing sands of different grain size, clay content, and density, but in testing the same heap sand of practically constant grain size, density, and other properties the assumption is justified.

The same author[2] describes a *compression moisture method* which is even more rapid than that mentioned above. For a given sand, the length of a rammed sand specimen is inversely proportional to the moisture content. The procedure uses a sample of sand weighing one hundred and seventy (170) grams, which is rammed in the permeability specimen tube in the Standard manner. The rammer is equipped with an indicating hand which registers accurately the length of the rammed specimen, as described in the section on ramming. If desired, the scale of the indicator may be calibrated in percent of moisture instead of height of rammed specimen. For practical foundry control it is not necessary to know the absolute moisture content in tempering the sand, as simply relative moisture content will give equally satisfactory results.

The compression test for moisture can not be used to determine the correct percentage of moisture of a sand for which it has not been calibrated, but only the relative variation of moisture, which is all that is required in a foundry for controlling the tempering of heap sand. Dietert states that this method will give readings varying not more than two-tenths or three-tenths from the correct readings of moisture content as determined by the Standard oven test. As all satisfactory molding sands should possess at least a leeway of one percent moisture for satisfactory tempering it is seen that this method is well within the limit required for foundry control.

[1]Transactions of the American Foundrymen's Association, Vol. 32, part 2, page 28.

[2]Dietert. Transactions of the American Foundrymen's Association, Vol. 33, page 751.

CONTROL OF RAMMING

With controlled moisture content or temper of the heap sand it is comparatively simple to check the degree of ramming actually given in the mold by permeability test of the mold. For this purpose special apparatus may be used[3] or the Standard A.F.A. permeability apparatus may be carried out in the foundry and used for actual testing of molds.[4]

If the permeabilities of the molds vary appreciably it is a direct indication that the ramming of the mold must be at fault, because the moisture and the permeability of the heap sand are accurately controlled by the method described.

[3]Harrington, Wright and MacCombe, Transactions of the American Foundrymen's Association, Vol. 32, part II, page 98.

[4]Harrington, Wright and Hosmer, Transactions of the American Foundrymen's Association, Vol. 34, page 307, 1926.

RECLAMATION AND IMPROVEMENTS IN PHYSICAL PROPERTIES

Changes in the property of the molding sand itself are generally brought about by mixing new sand to bring up the bond or permeability of the heap sand, or adding

other material such as clay or colloidal matter to modify the properties of the sand so that they will more nearly approach those considered best for the conditions of use. Obviously, in preparing synthetic mixtures of this kind, it is absolutely necessary to know the desired properties, if the mixture is to be made in any really intelligent fashion.

NEW SAND ADDITIONS

Perhaps the most common method is to add new sand to the heap sand in order to maintain the desired minimum strength and permeability. In adding new sand, the sand grains themselves may be considered simply as carriers of the active bonding material, unless the added sand is of such size distribution as to tend to increase the permeability of the sand. Under these conditions, the addition of the sand particles themselves are the important consideration. It would then seem logical to add simply the active bonding material to a heap sand in order to bring up its bond. But generally, the addition of clay or ordinary colloid matter to the sand, is not satisfactory. Numerous investigators have found that mulling the sand for a relatively long period after mixing clay to improve the bond in this manner, causes an intimate mixture of the clay and the sand which then has the desired property.

MULLING

One of the first papers reporting the effect of mulling on molding sand was that by Wolfe and Grubb.[5] A number of mixtures as shown in Table XXXVII were investigated, in which local sand No. 1 and No. 2 are those produced in Northern Ohio, and Gallia refers to the red sand a in Gallia County, Ohio. Local No. 1 and No. 2 correspond to Albany No. 1 and No. 2 respectively in permeability and bond. The Gallia sand shows a high permeability and high bond with clay content of 27 by the A.F.A. test, and a dye-adsorption of 1700.

Mixture Numbers	1	2	3	4	5	6	7	8	9
Percent heap sand in mixtures	100								
Percent refuse in mixtures		100	60	60		88	85	80	95
Percent Local No. 1 in mixtures			30						
Percent Local No. 2 in mixtures				30	90				
Percent gallia in mixtures			10	10	10	12	10	10	
Percent Albany No. 2½ in mixtures							5	10	
Percent Albany slip in mixtures									5
Method of mixing	S*	S	R**	R	R	R	S	R	S
Bond of mixture	160	139	134	139	156	133	144	133	138
Perm. of mixture	20	28	23	26	45	25	20	30	19
Bond after mulling 10 minutes	178	155	100	198	212	169	158	143	178
Perm. after mulling 10 minutes	19	23	19	21	43	19	19	37	16

*Screen method. **Royer method.

Table XXXVII. Effect of Mulling on Various Sand Mixtures.

[5]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 1.

Strength and Bond

It will be noted that the maximum bond strength is developed only after the mixture is mulled for about fifty minutes or longer, depending upon the properties of the mixture. Mulling alone without the addition of new bonding material serves to restore considerable bond strength to a refuse sand, and has much the same effect on the regular heap sand. It was also noted that the working properties of the heap sand were greatly improved by this treatment and the effect on molding losses was evident for several days.

The effect on the strength of the sand as determined by its tensile and compressive tests was similar to the effect of mulling on the bond as determined by the A.F.A. method. The dye-adsorption value was practically unaffected by mulling. This interesting fact leads the author to suggest that the dye-adsorption test probably indicates those characteristics determining the potential bond or the maximum strength that can be developed in a given sample, while the actual tensile compression and bond test indicates the actual strength of the sand existing at anytime.

Grain Size

Mulling seems to have no effect on the average grain size, at least during the first 100 minutes. It is known that dye-adsorption is an equilibrium condition between the surface of the sand grains and clay, and the dye in water solution. The fact that the grain size is not affected by time of mulling, and that the dye-adsorption value remains practically constant, may simply indicate that the active surface of the sand is not changed by mulling. In so far as the active surface of the sand grain determines the potential or maximum bond of the sand, the dye-adsorption value may be a correct indication of the potential bond of the sand, if such a term has any definite meaning.

Permeability

The permeability of the sand was reported to be generally decreased slightly during the first few minutes of mulling, and then to remain practically constant until the sand is mulled for such a long time that the bond strength begins to decrease. In their report Wolfe and Grubb did not state whether or not the sands and mixtures were retempered after mulling. Apparently this was not done, and the loss in permeability was due to a loss in moisture which occurred during the mulling operation.

A later and more thorough investigation by A. V. Leun[6] of the effect of mulling on the physical properties of sand took into account the effect of drying of the sand during mulling. It was found that the water content of the sand was decreased from about six percent to approximately three percent while mulling for one hundred twenty minutes, and that the decrease in moisture is practically a straight line function of the time of mulling. Water content is a very important variable in determining the properties of molding sand, and the earlier results maybe entirely contradicted because the proper allowance was not made for this important variable.

After several unsuccessful attempts to prevent the loss of moisture during mulling, water was added to the sand during the process at the proper rate to maintain practically constant water content. The results of these tests are similar to those reported by Wolfe and Grubb in

that all cases the strength seems to increase with more or less rapidity with time of mulling up to about seventy-five minutes, but, as might be I expected, the results regarding permeability are quite different as it was found in the great majority of cases that increasing the time of mulling increases the permeability of the sand if the moisture content is maintained.

The second investigation covering a wide variety of sand clearly indicates that mulling invariably improves the properties of a sand which has been used for some time and is almost indispensable in obtaining the best possible results from such artificial or synthetic mixture as are commonly used.

The effect of moisture content on the sand during mulling is a very important factor. Generally the sand should be mulled with insufficient water rather than with an excess of moisture.

Apparently the increase in permeability frequently noticed in mulling sands is due to the agglomeration of the particles as they are rolled around in the muller. This is generally more pronounced in sands which have a relatively high clay content.

[6]A. V. Leun. Transactions of the American Foundrymen's Association, Vol. 34, page 269 1926.

CLAY ADDITIONS

The bonding and rebonding of molding sand heaps by the addition of clay is not a new problem, as this is the common practice in steel foundries which use a highly refractory sand composed of almost pure silica and a refractory clay. In gray iron foundries the casting temperature is sufficiently lower than in the steel foundries to permit the use of less refractory materials and natural bonded molding sands are usually depended upon even for rebonding heap sand, as described. Harrington, Wright and Hosmer[7] have found it possible to rebond heap sand by the addition of clay and the use of an effective mixer such as a muller or a paddle-type mixer. In general they found that the paddle type mixer gave higher permeabilities and only slightly lower strength than the muller. However, in treating the heap sand with only clay additions over a period of two or three months, it was found impossible to prevent scabbed castings. The addition of a small percentage of new sand, varying from four to eight percent, was sufficient to produce within the sand such characteristics as to eliminate this tendency to a great extent. It was noted that heap sand rebonded by the addition of clay showed slightly lower permeability and compression strength than heap sands rebonded by the addition of new sand; also that sandb rebonded entirely by the addition of clay seemed unable to develop strength with increased clay content.

7Transactions of the American Foundrymen's Association, Vol. 34, page 307, 1926.

Clay Alone Inadequate

These facts indicate clearly that the simple addition of clay for a rebonding material in molding sand, even when the mixture is properly mulled to develop the best working properties, is not adequate to entirely restore the natural bond in the sand. Harrington, Wright and Hosmer noticed a decrease in dye-adsorption with an increased clay content, clearly showing that the clay possesses a lower colloidal value as determined by the dye-adsorption test than the natural sand itself and certainly that bond, clay content, and dye-adsorption are not by any means representative of the same physical property. The results of outwork on the relation of colloidal ferric hydroxide to the bond of natural molding sands definitely indicates that the desirable properties possessed by natural molding sand can be duplicated only by supplying a colloidal hydro-jell bond in addition to the clay bond. In adding new sand as are bonding agent, much colloidal matter is added with the bond carried by the new sand.

Exactly what contribution the colloidal bond makes to desirable properties of the sand is not known. But it would seem to be some effect on the dry strength or properties of the sand in the dry rather than green condition. The tendency toward scabby casting when such colloidal matter is lacking, and the high dry strength of sands bonded by colloidal ferric hydroxide have been noted.

It seems reasonable to expect some relationship between these two facts. The data obtained from an extensive investigation into the possibilities of the use of colloidal ferric hydroxide and clay as a means for rebonding heap sands should prove of practical and theoretical value.

Dry Strength Important

In discussing the scabbing of castings, H. W. Dietert[8] reports that it has been his experience that scabbing is brought about by the use of a sand possessing a too high green strength, and that he has time after time eliminated scabs by simply reducing the green strength of the molding sand. Because it may be the tendency of the molder to increase the green strength in order to lighten his work in ramming or to be sure of getting a good mold, perhaps the increased green strength of the sand causes the molder to use less water or to ram less with disastrous results to the dry strength. Hansen[9] has clearly shown that the dry strength increases rapidly with increased ramming. It may be that the scabbing is due rather to a low dry strength of the mold, because the mold was insufficiently rammed to develop a necessary dry strength, when the green strength of the sand was excessive.

[8]Transactions of the American Foundrymen's Association, Vol. 34, page 324, 1926.

[9]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 57.

Use of "Impure" Clays

A. C. Porter[10] reports his experience in using an impure clay from a brick yard added to the burned out sand as a slip composed of about equal weights of clay and water mixed in a muller. After four months of rebonding sand in this manner without the addition of new sand, no difficulty had been observed. This may be due to the fact that the impure clay which was obtained from the brick yard contained sufficient colloidal ferric hydroxide or similar material so that the proper balance between clay and colloid was maintained, or it may be due to the fact that there was sufficient colloid matter in the sand originally to stand the addition of an appreciable amount of clay before any trouble might be experienced as this practice was continued over a longer period.

Our investigation has shown that the bonding power of clay is destroyed more rapidly than that of the adsorbed ferric hydro-jell on the sand grain. This fact may explain why efforts to rebond heap sand by clay additions alone have not been entirely satisfactory.

[10]Transactions of the American Foundrymen's Association, Vol. 34, page 325, 1926.

SAND HANDLING IN FOUNDRIES

Many practical foundry men in reporting the results of their experience in the transactions of the American Foundrymen's Association call attention to the important advantages in using proper sand control in the foundry. In general, however, the customary method of a foundry does not lend itself readily to treating the sand or keeping it in proper condition by mechanical and chemical treatment. The sand is usually available to the molder in the form of a heap on the foundry floor. The molds are prepared from this heap sand, then the metal is poured, and finally, the sand is returned to the heap where it is retempered and mixed for the next day's operation.

Max Sklovsky[11] calls attention to the fact that under this method of operation, a molder handles forty times as much weight in sand as compared with his production in castings, in the dumping process about nine times the weight of castings, and in cutting the sand, about eighteen times the weight of castings, making a total of sand handled by labor about sixty-seven times that of the casting produced. Not only is this a tremendous manual effort but, as the total weight of sand in use in the foundry greatly exceeds that of the casting produced per day, the difficulty of treating this large amount of sand to maintain the desired property for the best production of casting is a real problem.

Sklovsky describes a method of handling and treating molding sands in a foundry, which is radically different from the conventional method and promises important advantages in that the sand is handled entirely by mechanical conveyors which bring the treated sand to the molder and carry the dump sand to the treating equipment. During anytime the number of filled molds is less than five percent of the total daily production. This amounts to about two percent of the total sand in the system.

Such a system not only saves the large amount of labor in handling the sand in the customary manner but offers an important advantage in the ease with which the sand may be treated. It is not necessary to carry the sand by means of the crane to the treating equipment and then back to the heap, as would be necessary in the more conventional type of foundry, as the sand is carried by the conveying system to the treating equipment, and after treatment is carried by a similar system to the molder.

Problems of this kind must always be considered in the light of local foundry conditions. Perhaps in many cases it is still more economical to purchase new sand as required, discarding the old. Present conditions are making this practice more and more expensive, and many foundries are turning their attention to the possibility of reclaiming their old sand and in some cases actually investigating the use of synthetic sand in iron founding. The larger the foundry, and the more sand that is used, the greater the economy in such a procedure.

[11]Transactions of the American Foundrymen's Association, Vol. 33, page 708.

SYNTHETIC SANDS

In many ways, preparation of synthetic sands seems to offer the ultimate solution in much the same way as it has been found to be the solution to the problem of casting steel. The differences between the melting point of the iron which is being poured in the mold and the fusing point of the clay bond material is so slight that the differences between the casting temperatures of iron and steel are sufficient to preclude the use of natural bonded molding sand in making steel castings.

Chapter VI. CLASSIFICATION OF SANDS

Sands as well as other materials may be classified in a number of different ways. Classification on the basis of origin has already been given in the first chapter. In this chapter sands will be classified according to their uses, and to those physical properties susceptible to classification or description which are most important in determining the practical uses of sand.

MOLDING SAND

The most important classification of molding sand is that based upon the physical properties determining the utility value of the sand. The need for standardization and classification of these physical properties is generally recognized and such standards are being adopted rather rapidly by the American Foundrymen's

Association. The more reliable guide so far has been the results obtained in actual shop practice, as compared to the physical properties determined by the methods of tests enumerated in the previous chapters. At present no entirely satisfactory correlation can be made of the behavior of the sand in molds, with its physical properties, until the necessary information has been accumulated and interpreted in terms of the Standard Tests.

PHYSICAL PROPERTIES

FINENESS OR GRAIN SIZE

The most easily classified property of molding sand is the fineness. For this reason we find that most attempts to grade molding sands are based primarily on fineness.

Perhaps the oldest system of grading sand in this country is the Albany System, or Albany Grade Numbers, based upon fineness or average grain size as indicated in Figure 4. The tentative standard grading classification for foundry sand adopted by the American Foundrymen's Association[1] is based upon a grain fineness number and a clay content classification.

Relation Between Fineness and Permeability. Grain size or fineness, and grain size distribution affect the permeability of the sand, its green strength, dry strength and other properties, as well as being a fundamental property of the sand itself.

In grading molding sands, C. A. Hansen[2] has found the average permeability of Albany sands to be fairly well represented by an exponential function of the grain diameter in mills, or of the Rittinger Index as follows:

$$P=3.1XD.^{1.5}$$

or approximately

$$P=3.1X2^{n+1.5}$$

where

P is the permeability, D the diameter in mills and n the Rittinger Index.

The permeability of molding sands depends upon other factors than simply the average grain size, and any such relationship must be only approximate.

Another approximation3 is given by the Sub-Committee of the American Foundrymen's Association on grading sands, which studied a total of seven hundred and twenty-seven natural sands including sixty-four sands from the State of Michigan. The A.F.A. grain fineness number for these samples was calculated, the data assembled and classified in respect to grain fineness, clay content, dye absorption value, permeability, and bond. Upon plotting the permeability averages against grain fineness averages, it was found that the points lay very close to a curve represented by the equation:

$$P=\frac{187{,}000}{F.^{1.8}}$$

Where P is permeability, and F. is A.F.A. grain fineness. Seventy-three percent of the samples studied came within plus or minus fifty percent of the values computed by the formula, which does not take into consideration clay content, distribution of grain size, or other factors, which are important in determining permeability. An alignment chart taking into consideration both grain fineness and clay content is also included which approximates more closely the permeability of new sand.

These two studies indicate that grain fineness is the main factor in determining the permeability of a sand.

[1]Transactions, Vol. 35, page 193, 1927.

[2]Transactions of the American Foundrymen's Association, Vol. 34, page 393, 1926.

[3]Transactions of the American Foundrymen's Association, Vol. XXXIV, page 504, 1926.

CLAY SUBSTANCE

In many ways *clay substance* and *silt*, may be considered as part that property identified as *fineness*, as the distinction between sand grain silt and clay, is based fundamentally on differences in sizes of particles, In fact some analyses as reported by the American Foundrymen's Association are based on 100 percent including sand grains, silt, and clay substance; but in classifying sands the A.F.A. grain Fineness Number already described is based on 100 percent excluding the clay substance.

The latter plan is preferred because the industry has always so classified sands independently on the basis of grain size or texture, and clay content or bond. The distinction between sands containing a relatively large amount of "clay substance" or "bond" generally classified as strong sands, and sands containing a relatively small amount, classified as weak or lean sands, has been made ever since sands were first used for making metal castings.

Recognizing that the clay content is not identical with the bond of the sand, the classification of sands into groups according to their clay content, as suggested by the Tentative Standard Grading Classification for Foundry Sands of the American Foundrymen's Association, will prove of value in giving some definite numerical scale to the relative terms strong and weak as applied to molding sands. In this classification the clay content is designated by a letter in a series from A through J according to the following classification:

Clay Content Classification

Class	Clay Content Zone
A	0.0% to but not including 0.5%
B	0.5% to but not including 2.0%
C	2.0% to but not including 5.0%
D	5.0% to but not including 10.0%
E	10.0% to but not including 15.0%
F	15.0% to but not including 20.0%
G	20.0% to but not including 30.0%
H	30.0% to but not including 45.0%
I	45.0% to but not including 60.0%
J	60.0% to but not including 100.0%

This tentative Standard Grading Classification of the American Foundrymen's Association includes grain fineness and clay content which together determine approximately the permeability and the strength of the sand. With the possible addition of grain size

distribution, it does not now seem advisable to complicate further the grading of sand.

Permeability and Bond Strength vary so much with moisture content and other conditions of test or use that, for the present at least, it seems better to tabulate this information separately.

DURABILITY

Another important factor in determining the relative grade of molding sand, is the durability of the sand. It seems that the most satisfactory present method of determining the durability of the bond, is to heat the sand at 600°F. for two hours. The percent of original bond strength remaining after this treatment at that moisture content giving the maximum bond strength in each case, may be regarded as the relative durability of bond.

Uses

With this information it is possible to estimate the purpose for which the sand may be used successfully, provided we know the properties of sand which has proved successful in practice.

Although many foundries have determined the properties of sands which may be used successfully in their own plants only little information of this kind has been published. H. W. Dietert[4] gives the properties of sands that are used successfully in the plants of the U. S. Radiator Corporation. For boiler molding sands, the desirable permeability is between 35 and 45, with a compressive strength of from two to three and one-quarter pounds as determined by Dietert's method. The sand should have a fairly wide moisture range giving permeability and bond strength within these limits, with the maximum approximately between seven and eight percent of moisture. Dietert reports that the sand is kept within these limits by the proper addition of an adaptable new sand, as open sand, or bonding sand, and by correct tempering. In purchasing new sand the salesmen are requested to submit representative samples which can be duplicated to within twenty percent of test reading in car lot shipments. These samples are then tested for permeability and compressive strength over the possible working range of moisture content, as well as for clay content, fineness, base permeability, lime, and durability. The percent variation in moisture required to make a change of two and one-half cc. in permeability is regarded as the moisture working range. Sands having a moisture working range of less than one and one-half are difficult to temper correctly in the heap. Some sands have a moisture working range of about seven percent.

Generally a sand which loses not more than twenty percent of its compressive strength when heated to 600° F. for two hours is desired. But this figure may be varied to suit local conditions. For example, if a foundry is located close to a large deposit of molding sand which can be obtained at relatively low cost, it would prove more economical to use this sand even though less durable than other sand not so readily obtainable, to save high freight rates.

Dietert calls attention to the great importance of *base permeability* because it compares the permeability of all sands under similar conditions. Some sands of high clay content show a low permeability due to the presence of a large amount of clay. Yet, when these sands are added to the heap they may have a very open grain structure which will tend to increase the permeability of the heap. This open grain structural giving high permeability is shown on determining the base permeability but not in the natural permeability.

Later Dietert[5] tabulates the permeability values known to give satisfactory results in his foundry for various purposes as follows:

Kind of Work	*Permeability*
Light gray iron, hand rammed	20 to 30
Medium gray iron, hand rammed	30 to 40
Radiators cored, hand rammed	30 to 40
Stove plate—Squeeze	8 to 12
Medium plate—cores or flat squeeze	12 to 20
Flat boiler section, 200 pound to 900 pound jolt	40 to 55
Flat boiler section, 200 pound to 900 pound Sandslinger	50 to 70
Round core sections, closed cheeks, jolt stripped	55 to 70

and compression strength as determined by Dietert's compressive test as follows:

Kind of Work	*Compressive Strength*
Squeezer plate sand	1.0 pounds
Sand slinger sand	0.8 pounds
Jolt roll over sand flat work	2.3 pounds
Radiator hand rammed sand	1.0 pounds
Jolt strip for closed cheeks	0.6 pounds
Hand rammed floor molding sand medium work	1.3 pounds

These values apply primarily to the foundries under Dietert's control and may or may not properly represent the desirable properties of sand for use in other foundries.

The information on sand gained by these Standard Tests has not yet been accumulated for a sufficiently long time to enable more definite recommendations to be made. As foundrymen continue to test sand carefully under actual working conditions these data will become available and judging or grading molding sands will become more of a science and less of an art.

[4]Transactions of the American Foundrymen's Association, Vol. 32, Part II, page 24.

[5]Transactions of the American Foundrymen's Association, Vol. 34, page 224, 1926.

OTHER FOUNDRY SANDS

Sand is used in foundries for other purposes than as a naturally bonded molding sand. Sand is used to prepare the cores in the castings, and also to serve as the base of synthetic molding sands as used in the steel foundries.

CORE SAND

Core sand is composed usually of silica grains but frequently contains from ten to thirty-five percent feldspar and other minerals. It carries little or no bonding material as in use it is always customary to add this to the sand. In general, the sand should be free from silt, clay, or other extremely fine material, and the grains may be either rounded or angular.

Moldenke[6] claims that cores in general require more strength than molds as they are subject to more and rougher handling, as the cores project into the mold they must not only withstand bending strain through static and fluid pressure, but the gases formed within the cores must be given every opportunity for rapid escape without flowing into the metal. Finally as the cores must be removed after shaking out the mold, the bond of the cores must be such that it is readily destroyed by the heat of molten iron after this has been set. To give the best possible venting of gases a core sand should have uniform sand and round grains.

[6]Principles of Iron Foundrying, page 300.

Bond

Since any clay present would tend to bake the grains together and thus make it difficult to remove the core after casting, the required bond should preferably be a substance with strong adhesive powers so that only a small amount need be used, and it should be able to withstand heat long enough to prevent the metal from cutting the surface as well as entering the pores, and yet be more or less completely destroyed by the heat from the molten iron or metal. Core binders are generally organic substances such as linseed oil, rosin dextrin or mixtures.

Testing

In testing core sands much the same methods are used as in testing molding sands, except that, as artificial bonds are used, the synthetic mixtures are generally tested to obtain a better working idea of the mixture rather than simply of the natural unbonded sand. As we are not concerned with organic binders for core sands in the present discussion the reader is referred to those readily accessible articles which deal with this matter.[7]

[7]Lane, The Journal of the American Society of Mechanical Engineering, Vol. 33.
D. A. Crosby, Transactions of the American Foundrymen's Association, Vol. 35, page 148, 1927.
H. L. Campbell, Ibid., Vol. 35, page 158, 1927, and Vol. 34, page 558, and page 567, 1926.
Harper and Stevenson, Ibid, Vol. 33, page 817.
A. B. Grubb, Ibid, Vol. 33, page 808.
C. A. Hansen, Ibid, Vol. 34, page 577, 1926.

STEEL SAND

While many of the naturally bonded sands used as molding sands may contain as little as 55 to 60 percent of silica (generally from seventy-five to about ninety percent), sands used for molding steel should consist of practically pure quartz grains either angular or rounded in shape, to withstand the higher temperatures necessary in casting steel. Generally steel sands contain more than 90 percent of silica before the addition of the artificial bond which may be fire clay or some organic binder. The most important property of steel sand appears to be high refractoriness.

FIRE SAND

Fire or furnace sand is silica sand used to line furnace bottoms and wells, especially open hearth furnaces making steel by the acid open hearth process. It is also largely use din forming the bottoms of copper refining furnaces and reverberatory copper smelting furnaces.

A high silica content is usually essential although a small amount of bonding material is frequently desirable to hold the sand in place until the furnace lining has been fired or burned in. If this bonding material is lacking, it is usually added in the form of plastic fire clay. The latter procedure is more desirable than seeking a natural bond in the sand, as the natural bond may decrease the refractory properties of the sand.

Sand as low as 80 percent in silica has been used in some cases[8] but a silica content greater than 95 percent is usually specified.

Generally a product graded from coarse to fine is considered better than one of uniformly sized grain, as the graded sizes assist in bonding, fill voids between the larger grains, and make the hearth more impervious. However, the finer grains sinter more rapidly during firing. Apparently large pieces are not always considered objectionable, as some producers market a crushed sandstone which has passed only a two mesh screen (about three-eighths (⅜) of an inch in diameter).[9]

In many ways fire sands are similar to fine steel molding sand. In some cases silica sand is first used as a steel molding sand, and the spend molding sand then used as furnace sand for the bottoms of the open hearth steel furnaces. This spent sand is reported to give better service than the new sand.[10]

[8]Barton, Refining Metals Electrically. The Foundry, Vol. 52, page 642, August 15, 1924.

[9]Rock Products, Silica Sand Plant of Newest Type, December 29, 1923, page 77.

[10]Weigel, Department of Commerce, Bureau of Mines, Bulletin 266, page 154.

PARTING SAND

Parting sand is pulverized fine quartz sand usually passing 100 mesh.

OTHER USES OF SAND

Although this Bulletin is concerned primarily with the possible use of sands in foundries, it seems proper to include here a brief discussion of the properties of sand

used for other purposes. This is particularly appropriate as many of the sands found in Michigan are not well adapted in their natural state for foundry purposes, but may be used, and frequently are used for other important industrial purposes.

Throughout the country the most important sands in tonnage and total value are those classed under the general head of STRUCTURAL SANDS, which includes all those varieties used in all forms of concrete, plasters, mortars, and similar purposes. A great deal of research work has been done on this class of sands by federal, state, and municipal agencies as well as trade associations, and various specifications and requirements have been formulated to cover the different kinds. This discussion is not intended to be at all complete but simply suggestive of the possible uses of the different kinds of sands found in Michigan. For those readers interested in learning more about the general uses of sand and silica the interesting bulletin by W. M. Weigel[11] is suggested.

[11]Technology and Uses of Silica and Sand. Bulletin 266, Department of Commerce, Bureau of Mines, 40c from the Superintendent of Documents, Government Printing Office, Washington, D.C.

STRUCTURAL SANDS

Specifications for structural sands are not standardized but to a large extent dependent upon supplies available in each locality. In general, structural sands may be divided into two large groups: *Building Sands* used in engineering and architectural structures, mortar and plaster, and *Paving Sands* used in all kinds of road and pavement construction.

Practically all specifications for the structural sand requires the sand to be clean and reasonably free from clay coated grains, lumps of clay, flat or elongated grains, vegetable or organic matter, chloride, and extremely fine material.

The upper limiting size of the coarser sands is usually placed at from three-eighths (⅜) to one-quarter (¼) of an inch.[12,13,14] Material retained on a 100 mesh sieve is called sand and that passing 100 mesh, silt or loam. Material removed by sedimentation or elutriation is sometimes called silt and is usually specified not to exceed three percent all grades. Generally the sand is desired to be uniformly graded from coarse to fine, and is not to contain an undue amount of any one size.[15]

Although some of the earlier specifications usually required sand grains to be angular or sharp, this requirement is omitted in modern specifications because it has been shown that good concrete, mortar plaster can be made from round grains. The sharp or angular grains do, however, possess slight advantage in tending to interlock in the concrete or mortar.

[12]U. S. Bureua of Standards, Wall Plaster, Its Ingredients, Preparation and Properties, Circulars 151, 1924.

[13]American Society for Testing Materials, Tentative Specifications for fine Aggregates, posed at its meeting June 25-27, 1924.

[14]Edmond Shaw, "What Makes a Good Concrete Sand".

[15]D. A. Abrams, "The Design of Concrete Mixtures", Chicago Materials. Research oratories, Louis Institute. Bulletin I, and Engineering News Record, Vol. 82, page April 17, 1919.
L. N. Edwards, "Proportioning of Materials for Mortars and Concrete". American for Testing Materials, Vol. 18, Part II, page 235, 1918.

Building Sands

Building sands include those sands used for concrete other than pavement, for mortar in laying stone and brick, and for plastering of all kinds.

CONCRETE SAND OR FINE AGGREGATE

In its tentative specifications for concrete aggregate (C 33-23T) the American Society for testing material states that *fine aggregate* consists of sand, stone screening, or other inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated grains, free from injurious amount of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam or other deleterious substances.

Screen Analysis. Fine aggregates shall preferably be graded from fine to coarse within the following limits:

Through three-eighths inch sieve	100 percent
Through number 4 sieve	85 percent
Through number 50 sieve, not more than	30 percent
Weight removed by decantation tests, not more than	3 percent

The three-eighth inch screen has a square opening of 0.375 inch and a wire diameter of 0.092 inch. The other sizes conform to those specified by the U. S. Bureau of Standards Screen Series (Table III).

The Decantation Test consists essentially in placing 500 grams of the properly selected sample dried at 110° F., in a pan or vessel of about nine inches in diameter and about four inches deep, covering with about 225 cc. of water. The whole is agitated fifteen seconds and allowed to settle fifteen seconds, and the water decanted through a 200 mesh sieve. This procedure is repeated with fresh water until the washings are clear. After returning all material retained on the 200 mesh sieve, the sand is dried at 110° F., weighed and the percent lost reported as silt, clay or loam.

Organic Matter. The presence of organic or vegetable matter in the sand has an important influence upon the setting time, and on the strength of the finished concrete.

As an indication of the amount of organic matter present, the American Society for Testing Materials recommends the following color test[16] and that no fine aggregate be used which gives color darker than the standard so determined.

A twelve ounce graduated clear glass bottle is filled to the four and one-half ounce mark with the sand to be tested. To this is added sufficient three percent solution of ammonium hydroxide in water to bring the total volume of sand and liquid to seven ounces after shaking. The bottle is then stoppered and shaken vigorously. After standing for twenty-four hours, the color of the

clear liquid above the sand is compared with the color of a standard solution, prepared by adding two and a half cubic centimeters of a two percent solution of tannic acid in ten percent alcohol to 97.5 cc. of a three percent sodium hydroxide solution placed in a twelve ounce stoppered bottle which is given the same treatment as the sand under test. The color of this standard solution is stated as 250 parts per million tannic acid.

[16]A. S. T. M. Standard Method, C 40-27.

SAND FOR BRICK MORTAR

No definite specifications for mortar sand for brick laying has so been proposed or adopted by either the American Society for Testing Materials, or the U. S. Bureau of Standards. In general, however, the sand used for this purpose should have the same general characteristic!! as that used for concrete, except that in face work where thin joints used, the coarsest grain should have a diameter less than the thickness of the mortar joint so that the brick or stone may be properly bedded.

PLASTERING SAND

Sand for plastering may be used with lime plaster, gypsum plaster or with a mixture of both. No general specifications are available, but the American Society for Testing Materials has adopted the tentative specifications (C 35-24T) for gypsum plastering sand, which will also apply to sand for other plasters. Such sands consist of fine granular material, naturally or artificially produced by the disintegration of rock containing not less than eighty (80) percent by weight of silica, feldspar, dolomite, magnesite or calcite, and shall be free from alkaline, organic or other deleterious substances.

Screen Analysis. The same specifications call for not more than 6 percent by weight on No. 8 sieve, not more than 80 percent on No. 50 sieve, not more than 6 percent through No. 100 sieve (Bureau of Standard Series, Table III.)

The U. S. Bureau of Standards[17] regards the requirement that eight (80) percent of the sand shall be retained on a number fifty sieve as an ideal to be approached rather than as a rule to be enforced. Johnson[18] also regards these specifications as too sever because they exclude many sands which are thoroughly satisfactory when used with gypsum. In general probably not more than about one-half of the sands actually used for plastering meet the specifications of the American Society for Testing Materials; in fact, only twenty-six (26) out of fifty-three (53) representative samples tested by Johnson, all of which were regarded as good in their respective localities, passed the above specifications.

[17]Wall Plaster, Its Ingredients, Separation and Properties, Circular 151, page 25, 1924.

[18]Sand for lime, gypsum and cement plasters, Rough Products, Vol. 28, page 54, March 21.

Paving Sands

Sand used in paving may be divided into three general classes: (1) that used in Sand for Concrete Pavements, (2) that used in Sand for Asphaltic or Bituminous Pavement, and (3) that for Grouting Sand and Sand for Sand Bed or Cushion.

SAND FOR CONCRETE PAVEMENTS

Although formerly a different grade was sometimes specified for the wearing surface than for the base if the pavement was laid down in two courses, modern practice now recognizes simply one grade. Preference should be given to sand composed of a mixture of coarse and fine grains, with the coarse grains predominating. In general, the sand should otherwise meet the specifications for concrete or fine aggregate sand. Even small amounts of organic impurities make the sand unsuitable.

Screen Analysis. The Bureau of Public Roads[19] recommends the following distribution of grain sizes:

Through one-quarter inch screen	100 percent by weight
Through one-quarter inch and retained on No. 10 sieve	5 to 25 percent
Through No. 10 and retained on No. 50	50 to 90 percent
Through 100 sieve, not more than	10 percent
Weight removed by elutriation, not more than	3 percent

[19]Vashell and Toms, Public Concrete Roads, U. S. Department of Agriculture, Bulletin 1077, page 4, 1922.

SAND FOR ASPHALTIC OR BITUMINOUS PAVEMENT

This class of sand includes that used for sheet asphalt binder and wearing courses and for bituminous concrete base and wearing courses. In general these sands must be composed of clean, hard, durable grain, free from a coating of clay or loam. The presence of a small amount of organic matter is not objectionable for sands which are to be bonded by a bituminous material, as the latter is itself entirely organic. In specifications covering sand for sheet-asphalt wearing course, it is usually further specified that sands be free from lump or balls of clay and the grain shall be tough, rough surfaced, and angular.

Screen Analysis. The tentative standard of the American Testing Materials for sand for sheet-asphalt and bituminous pavements (D 162-23T) requires the following grain size distribution:

Passing 200-mesh sieve	0 to 5 percent	
Passing 100-mesh sieve, retained on 200-mesh	6 to 25 percent	15 to 40%
Passing 80-mesh sieve, retained on 100-mesh	6 to 25 percent	
Passing 50-mesh sieve, retained on 80-mesh	5 to 40 percent	30 to 60%
Passing 40-mesh sieve, retained on 50-mesh	5 to 30 percent	
Passing 30-mesh sieve, retained on 40-mesh	8 to 25 percent	
Passing 20-mesh sieve, retained on 30-mesh	5 to 15 percent	18 to 50%
Passing 10-mesh sieve, retained on 20-mesh	5 to 15 percent	
Passing 10-mesh sieve	95 to 100 percent	
Passing ¼ inch screen	100 percent	

Hubbard and Jackson[20] approve similar requirements except to recommend that all the grains pass a 10 mesh sieve.

[20]Typical Specification for non-Bituminous Road Materials, U. S. Dept. of Agricultural, Bulletin 704, 1918, page 12.

GROUTING SAND

Grouting sand is used for making a thin cement mortar with which the joints between paving blocks or brick are

filled. The sand should comply with the same general requirements that govern other mortars.

Screen Analysis. As the grouting must flow freely into thin joints, the maximum size of grains permissible is reduced. The American Society for Testing Materials has adopted the following Standard Grading (D57-20) which has also been approved as Tentative American Standard by the American Engineering Standard Committee:

Through a number 10 sieve	100 percent
Through a number 20 sieve, not less than	80 percent
Through a number 200 sieve, not more than	5 percent

The sand is also subject to rejection if when mixed with Portland Cement passing the requirements of the Standard Specifications (C9) in a proportion of one part of cement to three parts of sand by weight, the resulting mortar at the age of seven and twenty-eight days possesses a tensile strength of less than seventy-five percent of that developed in the same time by mortar of the same consistency made of one part of the same cement and three parts of Ottawa sand.

SAND FOR SAND BED OR CUSHION

Sand used for the sand bed or cushion on which paving bricks or blocks are laid should be reasonably clean and free from foreign substances, although this requirement need not be as strict as for entering mortar of any kind. It is usually specified that such sand should pass a one-quarter inch screen, and not more than 5 percent be removed by elutriation, and that it be well graded from coarse to fine.

SAND FOR CEMENT MORTAR BED

When the sand is used for a cement mortar cushion, instead of loose sand, it should be free from lumps of clay and objectionable foreign matter. In addition to the limiting maximum size of one-quarter inch grain, the A.S.T.M. Specification (D 58-24) requires that at least ninety percent pass a number 10 sieve. That portion of the sand passing the number 10 sieve is also required to meet the same tensile strength test, when used as an aggregate in mortar, as required of sand for cement grout fillers (D 57-20).

The U. S. Department of Agriculture* gives the tentative standard methods for sampling and testing highway materials, including sand, as adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal aid road construction.

*Bulletin 1216, May, 1924.

GLASS SANDS

The quality of sand demanded by glass manufacturers depends largely on the kind of glass being made. Glass may be classified according to chemical composition or the predominating basic oxide, which has no interest for the sand producer; or on the basis of physical characteristics that are largely controlled by the quality of the sand used. On this basis glass may be separated into *optical glass*, requiring sand of the highest purity; *flint glass* for high-grade tableware that is to be polished and cut, requiring sand almost equal to that for optical glass; *plate glass* to be ground and polished, requiring a high grade sand; *window glass*, and plate glass which is not to be polished but used in the form of ribbed or wired glass, requiring a sand of less purity than the above; *green glass* which may contain much more iron oxide than that for the more transparent or colorless glasses, and which is used for containers such as carboys and bottles; and *different grades of amber glass* representing a rather special product for which a sand containing relatively large amounts of iron oxide is permissible and may be used.

Physical Properties

All glass sand should be screened to remove over-sized particles which may cause stones in the finished glass, as well as to remove pieces of vegetable matter and other rubbish. In general, glass sands should all pass a number 20 sieve. Some technologists and large producers claim that fines, that is material passing 100 mesh, are not objectionable, while others limit the amount of such material. As washing usually removes the excess fine material probably the main objection to fines is that they are likely to contain more impurities than the coarser products. Weigel[21] reports a petrographic examination of the fines obtained from a washed Ottawa sand when screened through a 150 mesh sieve, as showing an abundant amount of pyrite, dratite, or magnesian tourmaline, iron oxide, zircon, and a very small amount of hornblende.

[21]Technology and uses of Silica and Sand, U. S. Dept. of Commerce, Bureau of Mines Bulletin 266, page 151.

Screen Analysis. The following grading of glass sand has been recommended by the American Ceramic Society in conjunction with the U. S. Bureau of Standards, and, although not strictly followed by the manufacturers, may be considered as a desirable grading to be sought rather than required.

Through a Number 20 screen	100 percent
Through 20 on 40, not more than 60 or less than	40 percent
Through 40 on 60, not more than 40 or less than	30 percent
Through 60 on 100 not more than 20 or less than	10 percent
Through 100 not more than	5 percent

Shape of Grain. There has been considerable discussion as to the relative advantages of rounded grains or angular and sub-angular grains, due largely to competition between the Pennsylvania-Virginia and Illinois-Missouri districts, as the former produces a sand with angular grains and the latter a sand with rounded grains. Actually each shape of grain seems to be equally satisfactory in glass sand.

Chemical Properties. So far as physical properties are concerned the supply of glass sands would be almost unlimited. However, the chemical properties of the sand are generally far more important than its physical properties, because glass is essentially a chemical

product in which the sand is fused with other mineral reagents, and, provided the sand possesses such physical properties as to be used without difficulty, the properties of the glass depends entirely upon the chemical analysis of the materials used.

Perhaps the most important impurity in glass sand is iron oxide because of its discoloring properties on the finished product.

Although no definite standard has been universally adopted for glass sand, as manufacturers have varying opinions on the subject, the American Ceramic Society and the U. S. Bureau of Standards have formulated the following specifications covering the chemical composition for different grades of glass sand.

Qualities	Percent by Weight			
	SiO_2 Minimum	Al_2O_3 Maximum	Fe_2O_3 Maximum	$CaO—MgO$ Maximum
1. First Quality Optical Glass...	99.8 ± 0.1	0.1 ± 0.05	0.02 ± .005	0.1 ± 0.05
2. Second Quality Flint Glass Containers, tableware.....	98.5 ± .5	.5 ± .1	0.035 ± .005	.2 ± .05
3. Third Quality Flint Glass....	95.0 ± 1.0	4.0 ± .5	.035 ± .005	.5 ± .1
4. Fourth Quality Sheet Glass, rolled and polished plate...	98.5 ± 1.0	.5 ± .1	.06 ± .005	.5 ± .1
5. Fifth Quality Sheet Glass, rolled and polished plate...	95.0 ± 1.0	4.0 ± .5	.06 ± .005	.5 ± .1
6. Sixth Quality Green Glass, containers and window glass	98.0 ± 1.0	.5 ± .5	.3 ± .05	.5 ± .1
7. Seventh Quality Green Glass	95.0 ± 1.0	4.0 ± .5	.3 ± .05	.5 ± .1
8. Eighth Quality Amber Glass containers.....	98.0 ± 1.0	.5 ± .5	1.0 ± .1	.5 ± .1
9. Ninth Quality Amber.....	95.0 ± 1.0	4.0 ± .5	1.0 ± .1	.5 ± .1

Table XXXVIII. Specified Composition of Glass Sands. (Ignited Sample = 100 percent.)

Frequently first quality optical glass can be made from sands containing less silica, and more lime, magnesia or alumina than specified in the above table provided the iron does not exceed the recommended maximum. In making plate glass and other products a slightly higher lime content seems to be desirable as it aids in making the sand more easily fusible, without having deleterious effect on the finished product. It is also possible to use special reagents to partly neutralize the color due to iron oxide, when necessary. However, manufacturers of high grade glass prefer to obtain a sand with a minimum amount of iron, as iron is almost invariably picked up in other ways during the process. It is difficult to compare different analyses of sands reported from various parts of the world, as methods of analysis differ almost as much as the different requirements found necessary by different plants.

ENGINE SAND

Engine sand or traction sand is used to prevent the driving wheels of locomotives, street cars or other self-propelled vehicles from slipping on wet or slippery rails.

Engine sand should contain a minimum amount of dust and very fine particles and be free from over-size particles, rubbish, clay lumps, and any considerable clay coating which tends to retain or store moisture and form lumps. These precautions are necessary in order to insure a free flow of the sand through the feed pipes from the sand box to the rails. As the grains are crushed at once to a fine powder under the drivers, a fine pulverized silica would give the necessary tractive effect but would tend to pack, and flow sluggishly through the feed pipe, and be blown away before falling on the rail. Either rounded or angular grained sand is suitable, but the rounded grain seems to have a greater tendency to roll off the rail before being caught under the drivers. Round grains, however, if clean and hard are far more satisfactory than other sands that may contain a natural bond.[22]

The Pennsylvania Railroad system has no definite specification but it requires a high grade non-caking sand containing over ninety-five percent silica, and having sharp, clean grains of such size that practically all of it will pass a twenty mesh sieve, and be retained on an eighty mesh sieve. Actual analyses of sands used by this railroad[23] show from ninety-seven (97) to ninety-nine and six-tenths (99.6) percent through number twenty sieve, with ninety to ninety-eight per cent retained on number eighty. Sand of practically the same screen analysis has been found to be satisfactory by the Southern Railway Systems.

[22]Electric Railway Journal, Vol. 45, page 143, 1915.

[23]Weigel, Special Sands, Serial 2646, Bureau of Mines, October 1924.

ABRASIVE SANDS

All grades used for various abrasive and grinding purposes are classified as abrasive sands, including the natural sand grain but not the pulverized quartz or other forms of silica which have been reduced by intensive grinding. The principal uses may be classed into STONE SAWING SAND, GLASS GRINDING SAND, BANDING SAND, SAND PAPER SAND, and SAND BLAST SAND.

STONE SAWING SAND

Sand used for stone and marble sawing should be composed of tough and fairly uniform grains. Flat particles are objectionable, and fines are useless, as the coarser grains support the cutting edge leaving no work for the finer grains. However, unsorted sand is frequently used as it is cheap and readily available. Minerals softer than quartz are waste materials, as they are almost immediately crushed to powder and are of little cutting value. The sand is always used repeatedly by flushing the cuttings into a common sump, from which the sand is pumped. Material finer than 100 mesh is usually removed by flotation or by sedimentation before the sand is re-used.

There are no standard specifications for this material and each plant generally uses the most available material obtainable at a reasonable price. Both round and angular grains are used. It has been suggested[24] that a softer blade should be used with round grains, than for sharp sand as it would have less tendency to ride the round grain.

It is also reported that one company uses a sand of the following screen analysis:

Retained on 10 mesh	3.7 percent
Retained on 20 mesh	12.6 percent
Retained on 48 mesh	83.8 percent
Retained on 100 mesh	98.6 percent

The same company expressed its preference for clean sea sand as superior to this product if available at a reasonable price.

[24]W. M. Weigel, U. S. Department of Commerce, Bureau of Mines, Bulletin 266, page 140.

GLASS GRINDING SAND

Crude-rolled plate glass requires rough grinding to remove inequalities of the surface before final grinding and polishing. Sand is almost universally used for this purpose. Garnet and artificial abrasives are used to some extent but apply more particularly to the second grinding stage.

Specifications of sand used for glass grinding are not strict. Generally the cheapest available material that will do the work is used. For this reason local supplies of sand are generally used for abrasive purposes. The sand should be free from rubbish which might choke the pipe used in circulating the sand, and from large grains which may make deep scratches in grinding which are difficult to remove in the finishing process. Very fine sand and clay are objectionable only to the extent that they reduce the amount of quartz grains present.

Frequently the same sand is used for grinding as is used in making the glass mix, except that the latter is not dried or given a final screening. The Pittsburgh Plate Glass Company at Crystal City, Missouri, follows this practice using sand which passes 20 mesh and about ninety (90) percent retained on 150 mesh. The grains of this sand are decidedly rounded.

Chemical composition has no importance, except to indicate the presence of minerals which may be considered waste because they are too soft to do much grinding.

BANDING SAND

Banding sand is that which was formerly used to some extent for the second or semi-final grinding of plate glass and as an abrasive in beveling glass, but has now been largely superseded by artificial abrasives which cut more rapidly. It is a much finer sand than used for the first grinding of the glass and is also suitable for other than abrasive purposes if a very fine sand is desirable.

The screen analysis of samples of banding sand indicate that not more than four (4) percent is retained on 35 mesh and that at least ninety (90) or ninety-two (92) percent is retained on 100 mesh, and ninety-nine (99) or more retained on 150 mesh.

SAND PAPER SAND

At one time, sand was largely used for surfacing sand paper. Some crushed or graded quartz grains are still used for sand paper coating, but the introduction of the harder and faster cutting artificial abrasives and garnet, have practically eliminated the use of sand in preparing sand paper.

STONE AND MARBLE GRINDING SAND

Generally the abrasive sand used for rough grinding of stone and marble on rubbing beds is of the same grade as that used for stone sawing. Sharp angular grains are considered best, but as the cuttings are used over and over, the larger grains become broken so that a well rounded grain sand should prove equally satisfactory in the long run. Different stones and types of finish require different grades of sand, but for all work large grains and pebbles are objectionable and should be screened out. As for other abrasive sands, an excessive amount of reduces the efficiency. Generally a sand with hard tough grains which do not readily break down, prove the best.

SAND BLAST SAND

Formerly use of sand blast sand was confined almost entirely to the foundry to clean and remove inequalities from rough castings. Although this is still the most important application, its use has been extended to many other industries, such as the removal of paint from old surfaces, preliminary glass cutting, cleaning or renovating of walls of stone and brick buildings, preparing the surface of metals for the electrolytic bath, for enameling, and for engraving and carving designs and lettering on stone and marble. An attempt has also been made to use it to channel and cut out blocks of stone in the quarry, but only with partial success.

Fineness Grades

In the Midwest where only one fineness grade of sand can be produced from a particular deposit, the natural fineness of the sand deposit, most producers market their products under special trade-names. In the Eastern states, however, some attempts at standardization have been made, and the grades or different sizes are numbered. These grades are commonly classified as number one, two, three and four, number one being the finest and number four the coarsest. A number 0 is occasionally made, but it is too fine for most purposes.

Products of the same number obtained from different producers may vary due to difference in the shape of the grain, slopes of the screen, and variations in the screen mesh. However, tests of numerous samples sold under the different grade specifications indicate the following to be screen analysis of the different sizes:

Tyler Series	Cumulative Percent Sand Blast Sand			
Mesh	No. 1	No. 2	No. 3	No. 4
4	0	0	0	2.15
6	0	0	.06	74.0
8	0	0	8.0	96.0
10	0	.02	29.4	99.3
14	0.1	15.5	80.5	100.0
20	8.0	68.5	98.0	
28	42.2	92.0	99.8	
35	85.0	98.2	100.0	
48	98.5	99.6		
65	99.8	100.0		
100	100.0			

Table XXXIX. Screen analysis of sand blast sand.

Decided variations may be noted in the products of different plants, but disregarding small percentages of coarse and fine material, the following limits roughly indicate those of the different sizes:

Sand Blast No. 0	Through 35 mesh	and on 100
Sand Blast No. 1	Through 20 mesh	and on 48
Sand Blast No. 2	Through 10 mesh	and on 28
Sand Blast No. 3	Through 6 mesh	and on 14
Sand Blast No. 4	Through 4 mesh	and on 8

It would seem advisable for the producers to decide on standard limits for the screen meshes in order to avoid the present confusion. Occasionally, a still smaller size, Number 0, is used but not in general practice. Number 1 is used for light work, and where a comparatively smooth finish is desired as finishing automobile castings, brass, glass, and in removing paint. Generally manufacturers of brass and iron pipe fittings will use Number 1 exclusively. Similar work of a heavier character as for preparing iron bath tubs for enameling frequently require slightly coarser sand such as Number 2. Number 3 and Number 4 are used for the heaviest cast iron and steel work only. In general, very little Number 4 is used.

Shape of Grains

There is considerable discussion regarding the relative merits of sharp angular grains, and rounded grains. It is claimed that the sharp grains cut faster, and on the other hand, that the rounded grains give smoother work, and possess a longer life, that is, can be used over more often and make less dust.

The ability to resist crushing or shattering, or toughness of the grains is a very important property and will vary widely with different sands. However, no method of testing for this property has been developed other than actual tests under plant conditions.

Blasting sand is generally used repeatedly until the grains are reduced to dust. Plants that use large amounts have a separating and feeding system to remove dust and material too fine to be of any use. This material is generally wasted but it has been suggested[25] that it might be used as a foundry parting, mixed with dead core or gang-way sand for this cores, as a core wash, possibly as a foundry facing, mixed with clay for looting the covers of annealing pots and even in making concrete where discoloration due to particles of iron and steel is not objectionable.

[25]Abrasive Industries, Possible Uses for a Waste Sand Blast Dust, October 1923, page 305.

FILTER SAND

The use of sand for the filtration of municipal water supplies is becoming more important, as most cities that draw water supply from surface sources now use sand filters in their purification system. Sand filters not only remove sediment and suspended matter but also take out most of the bacteria in the water.

Filter sand has been produced in a number of states in varying amounts, but most of the high filter sand is produced in New Jersey with Illinois and Minnesota making an important contribution. Practically all filter sands used in Michigan come from Redwing or Castle Bay, Minn. The production of specially prepared filter sand is not difficult and any good sand bed can produce suitable sand if it can be washed clean and contains enough grains of the required size to warrant separation.

Grain Size and Shape

Good filter sand must be of fairly uniform size and within certain limits. It must be free from clay and organic matter and fairly pure quartz. Early investigations[26] showed that an excess of fine material increased the friction of the water flow and decreased the capacity of the filter bed to an impractical degree, and that the size of the finer particles rather than the coarser determined the effective size.

So far as has been determined, rounded or angular grains are equally efficient provided there are no flat or elongated grains. The size of grain in filter sands and the size distribution are expressed in two terms: (1) The *Effective Size*, expressed in millimeters, and determined as the theoretical size of the screen mesh through which ten percent of the sand would pass, so that ninety percent of the sand is coarser and ten percent of the sand, by weight, finer than the effective size expressed in millimeters. (2) The *Uniformity Coefficient*, the ratio of the size of screen mesh through which sixty percent of the sand will pass to the effective size as determined above.

The ordinary method of determining the effective size and the uniformity coefficient is to make a screen analysis of the dry sand. The cumulative percentages are then plotted against the size of the screen opening. The intersection of the curve with the ninety percent line gives the effective size. The size corresponding to the forty percent is read from the plot, divided by the effective size to obtain the uniformity coefficient. This can be done conveniently by use of coordinate paper, on which percentages are laid on the vertical axis and sizes of the screen openings on the horizontal.

Before accurate screens were obtainable it was customary to determine the size of grains passing a given screen by collecting the last grains passing and counting a known weight of the grain and, once their specific gravity was known, their diameters, assumed as spheres, could be calculated.

Specifications usually require that no grain shall be larger than a specified mesh, and limit the percentage of

very fine material or that passing 100 mesh. During the washing of the filter bed with counter current flow at a rate of about 2 feet per minute, all material finer than this collect in the top part of the sand bed and clog the filter. Sands with effective sizes of .2 to .7 millimeters are used, but those most commonly specified range from .35 to .65 millimeters. The uniformity coefficients vary from 1.25 to 1.8 with 1.5 to 1.6 as the average. Mr. Hern of the State Board of Health, Lansing, prefers sands of effective size 0.35 to 0.45 inclusive and uniformity coefficient less than 1.5.

[26]Allen Hazen, Analysis of Filter Sand, Massachusetts Board of Health Report, page 541 (1892).

Chemical Properties

A good filter sand requires a high silica content. Generally specifications require that not more than two percent shall be soluble in hot dilute hydrochloric acid or that the combined lime and magnesia calculated as carbonate shall not exceed two percent. Aside from this the chemical composition is seldom specified.

The amount of filter sand used is small in comparison with building and other sand. It gives satisfactory service for a long period of time and does not require frequent replacements. Sand used in connection with a water softening plant for some time becomes heavily coated with $CaCO_3$ and eventually must be replaced because the grains become too coarse. Preparation requires an extensive plant and careful supervision, and demands a higher price than is obtained for ordinary grades of sand. In many ways it is comparable to sand blast sand in cost and methods of preparation, in fact No. 1 sand blast sand is sometimes marketed as filter sand.

The price of filter sand varies considerably. The U. S. Bureau of Mines gives the average selling price as two (2) dollars per ton in 1924. When bagged and sold in less than carload lots, it sometimes sells for as much as ten dollars a ton, and four to six dollars per ton in carload lots is a common price for specially prepared sand meeting rigid specifications.[27]

[27]Bargess, Mechanical Analysis of Sand, Journal of the American Waterworks Association, Vol. 2, page 493, 1915.
Fritze, River Sand as Filter Medium, Journal of the American Waterworks Association, Vol. 2, page 390.
Langdon Pearce, The Rapid Filtration Plant at Evanston, Illinois, Journal of the American Waterworks Association, Vol. 2, page 172. 1915.
Smith, Size of Filter Sand at Lima, Ohio, Engineering and Contracting, Vol. 60, page 102, 1923.
True Importance of Filter Sands and Gravel in Filtration Plants, Engineering and Contracting, Vol. 59, page 121, 1923.
Turneaure and Russell, Public Water Supplies, New York, 1908.

SPECIAL SANDS

In addition to the sands which have been described, there are a number of special sands of considerable industrial importance, but produced in relatively small amounts. Practically no sand producer could confine his production to them alone, and they are usually prepared as the byproduct in the preparation of sand used for other purposes in larger quantities. For this reason special sands nearly always command a higher price than the usual grade of building sand; although local conditions may reverse this statement, as what is a special sand for one locality may be the major production of another pit.

POTTERS SAND

Potters Sand sometimes called *placing sand* is used in the ceramic industry by manufacturers of white ware, wall and floor tile, heavy clay products and refractories, as a packing in the saggers and between the shapes to keep the ware apart. It is of two general types, that used for white-ware and refractories, which must be low in iron and free from other easily fusible minerals, and that used for dark heavy clay ware which need not meet these specifications. There are two general grades, coarse and fine; the coarse being mostly sand between 10 and 40 mesh, and the fine mostly between 28 and 100 mesh. A good grade of glass sand would be suitable for most work. An extreme uniformity of grain is not essential, but coarse particles and dust are objectionable.

ROOFING SAND

Roofing sand as here defined is that used in coating prepared roofing for which white sand only is suitable, and is not the material applied to roofing built up in place. A rounded grain product is generally desirable but sands of sharp grains are used. The grain size is usually such that all of the sand will pass through the 20 mesh screen, and not more than 5 or 10 per cent through 65 mesh.

FLOORING SAND

Flooring sand is that used in asphalt flooring, which is made up of asphalt cement, a sand aggregate, and a fine absorbent mineral filler. The Federal Specification board [28] has the following specifications for sand when intended for government use.

"The mineral aggregate shall be sand and small gravel. It shall be clean, hard, and free from clay, silt, orgainic and other foreign matter and shall be properly graded from coarse to fine, so as to produce a mixture of greatest density and stability, and shall fall within the following limits:

Total passing a number	3 screen	100	percent
Total passing a number	8 screen, not over	60	percent
Total passing a number	30 screen, not over	40	percent
Total passing a number	100 screen, not over	7.5	percent

[28]U. S. Government Mastic Specifications for Asphalt Mastic Flooring, U. S. Bureau of Standards, 1924.

SANDS FOR CHEMICAL PRODUCTS

Sand is also used in the manufacture of sodium silicate or water glass, and artificial abrasives such as carborundum or silicon carbide. Although both sand and diatomaceous earth are employed in the manufacture of sodium silicate, by far the larger amount is made from sand, as it is suitable for the fusion process and is much cheaper than diatomaceous earth of suitable purity. Only high grade silica sand of especially low iron and alumina is permissible as alumina makes the resulting silicate difficultly soluble, and iron affects the color. A good glass sand is usually considered suitable if low enough in alumina. The general requirements are that the sand must contain at least 99 percent of silica, and over 1 percent of alumina, or over 0.5 percent of lime and magnesia combined, and less than 0.1 percent of iron. It is desirable that the sand should all pass a twenty mesh and remain on 100 mesh, which is approximately equal to the requirements for sizing of a high grade glass sand.

Generally a similar quality of sand is required in the manufacture of silicon carbide. For this purpose the presence of iron is particularly objectionable and more than a trace of lime, phosphorous or magnesia should not be present. Small amounts of alumina should not be particularly harmful. All grains should pass a twenty mesh sieve and the sand should be free from fines. One manufacturer states that the sand should be fairly free from dust and that material finer than 50 mesh must be removed.

Sand meeting these specifications is obtained generally from Pennsylvania and Illinois glass sand districts.

SAND FOR SAND-LIME BRICK

In sand-lime brick, sand has a two-fold function. Most of it acts simply as an aggregate making up the body of the brick which is bound together by the cementing material. The remainder supplies silica for the formation of the calcium silicate bond. For the latter purpose a certain amount of quite fine material must be present, as the action of lime on the larger grains under the temperature and pressure conditions is quite slow. Emley[29] gives the practical rule that about 15 percent must pass a 100 mesh screen. The balance should be well graded from coarse to fine to obtain a brick with maximum density and minimum of voids. An excess of large grains gives the brick a high compressive but a low tensile strength. Overlarge grains are objectionable as they make it difficult to mold brick which has sharp corners and edges. Sand for sand-lime brick varies in texture from about 48 percent to zero retained on a 20 mesh sieve, and 5 percent to zero passing a number 200 sieve.

If the fines in the sand do not suffice to combine with the lime, part of the sand must be finely ground before it is mixed.

Extreme chemical purity is not essential, but the sand should be reasonably clean and free from rubbish and other foreign material. Although clay tends to weaken the brick it is not particularly injurious otherwise, and its ill effect can be partly overcome by the use of additional lime. Sharp sand is usually considered better, but there is no reason why a rounded grain product will not make a satisfactory brick if enough fines are present.

[29]Manufacture and Properties of Sand-Lime Brick, U. S. Bureau of Standards, Technological Paper 85, 1917.

SAND FOR OXYCHLORIDE CEMENT

In compounding oxychloride cement or plaster various aggregates are used in the mix, which usually consists of sand, finely ground silica, and some other material, such as wood flour and a coloring pigment. The sand must be clean and free from clay particles or clay coatings. A sand that is decidedly finer than that used in Portland cement concrete gives the best results.[30] Apparently a sand much like a good glass sand is about the proper texture, or one, ninety percent of which will pass a twenty mesh sieve. The following screen analysis is recommended by the Dow Chemical Company:

Through 10 mesh	100 percent
Through 20 mesh	97 percent
Through 30 mesh	87 percent
Through 40 mesh	75 percent
Through 50 mesh	57 percent
Through 60 mesh	47 percent
Through 80 mesh	11 percent
Through 100 mesh	3 percent
Through 120 mesh	2 percent

[30]Dow Chemical Company, Oxychloride Cement Research, Service Bulletin No. 3, page 31, (1920).

SUMMARY

This brief outline of the properties of sand used for different purposes is intended simply to aid those readers who might be interested in the determination of the probable economic use of those sands described in the last part of this bulletin, and not in any way as an adequate discussion of the various uses of sand.