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.

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 of 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

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

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.

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.

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

[18]Moldenke, Transactions of the American Foundrymen's Association, Vol. 21, 1913.
[19]Transactions of the American Foundrymen's Association, Vol. 32, part II, page 47.

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.

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.

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

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

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 forced 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 centimeters

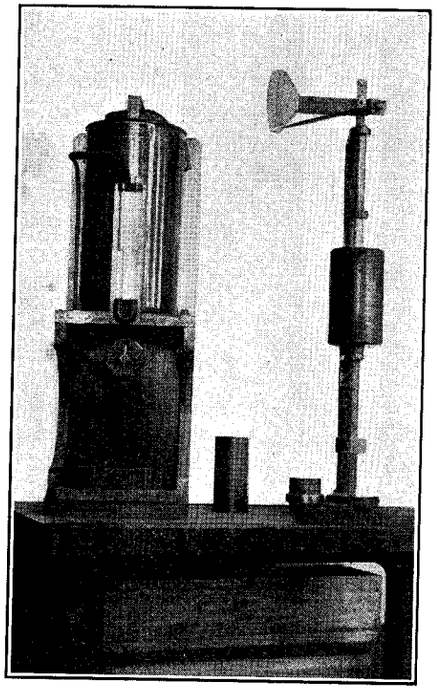


Fig. 6. Apparatus for permeability tests.

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.

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).

[21]Bulletin, Aug. 1, 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.

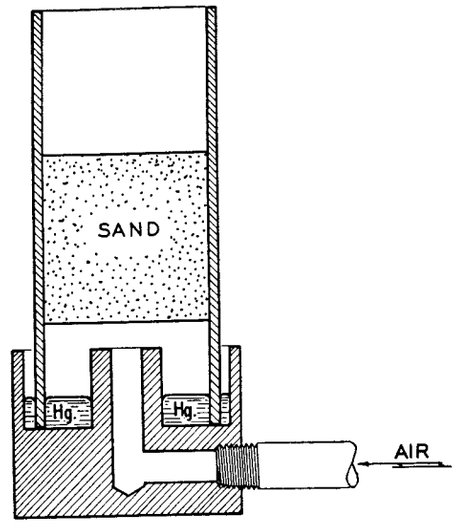


Fig. 7. Modified method of holding sand for permeability tests.

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 con-

tainer 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 to 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).

TABLE IX.—Base Permeability of Different Sized Mixtures.

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	8.9
20.0	42.8	14.3	14.3	14.3	19.2
14.3					

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.

TABLE X.—The Effect of Silt on Base Permeability.

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	58.1
85.6	14.4	27.8
83.4	16.6	21.4
81.1	18.9	20.1

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 in 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.

TABLE XI.—Effect of Grain Size and Grain Shape on Base Permeability.

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

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 sand 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.

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

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

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.

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

[24]Transactions of the American Foundrymen's Association, Vol. 31, page 687. 1924.
[25]Transactions of the American Foundrymen's Association, Vol. 32, page 57. part II, 1924.

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, and 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

[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.

oil system exerts one quarter of a pound per square inch on the sand 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, however, 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.

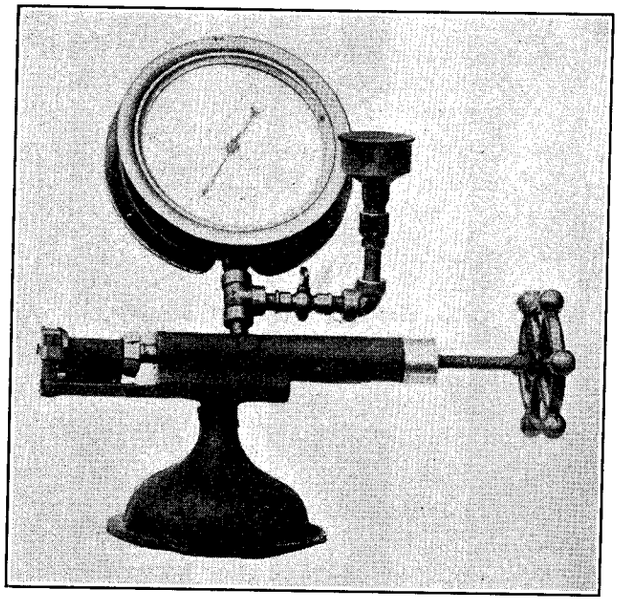


Fig. 8. Sand compression strength apparatus.

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.

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

[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).

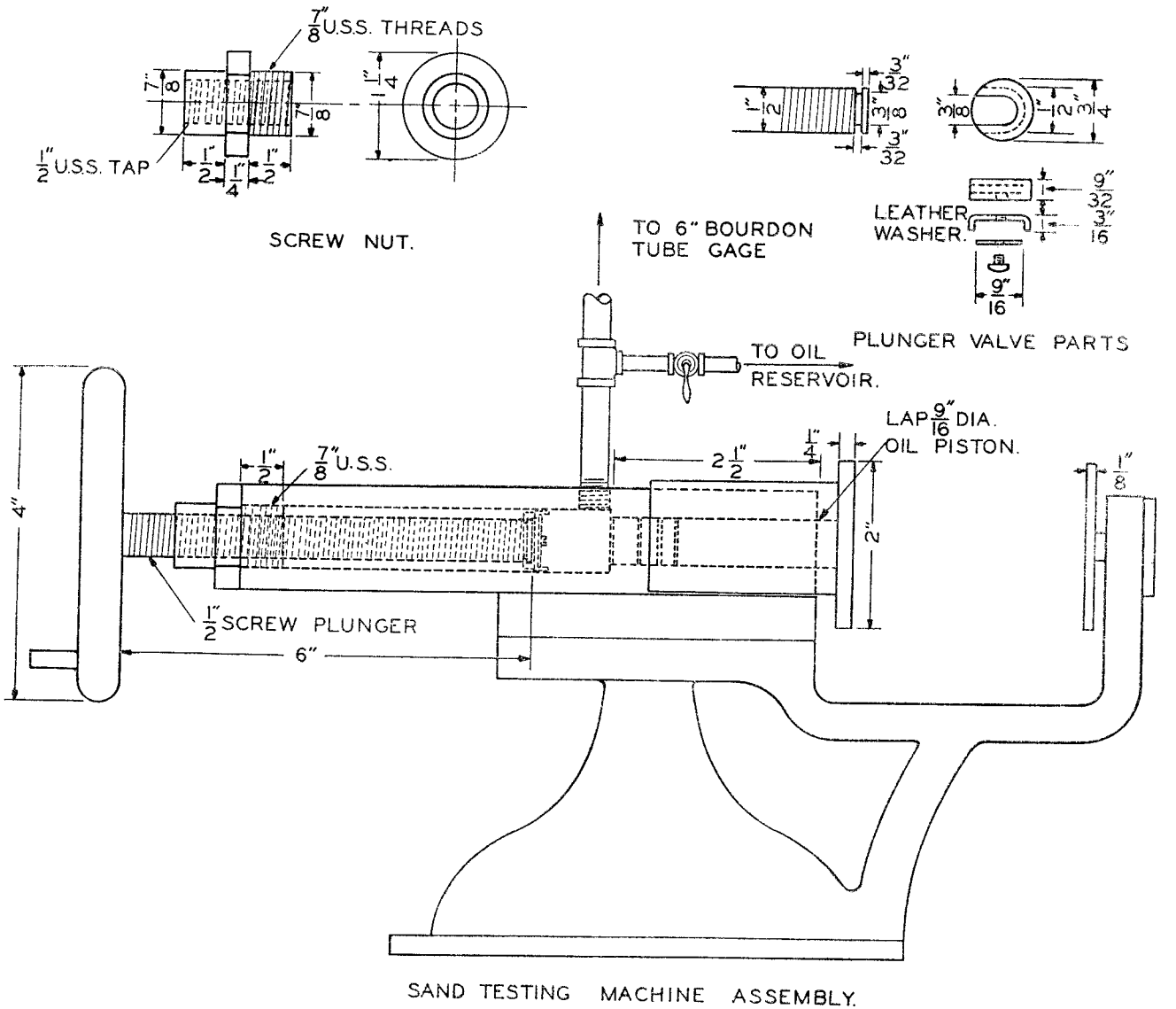
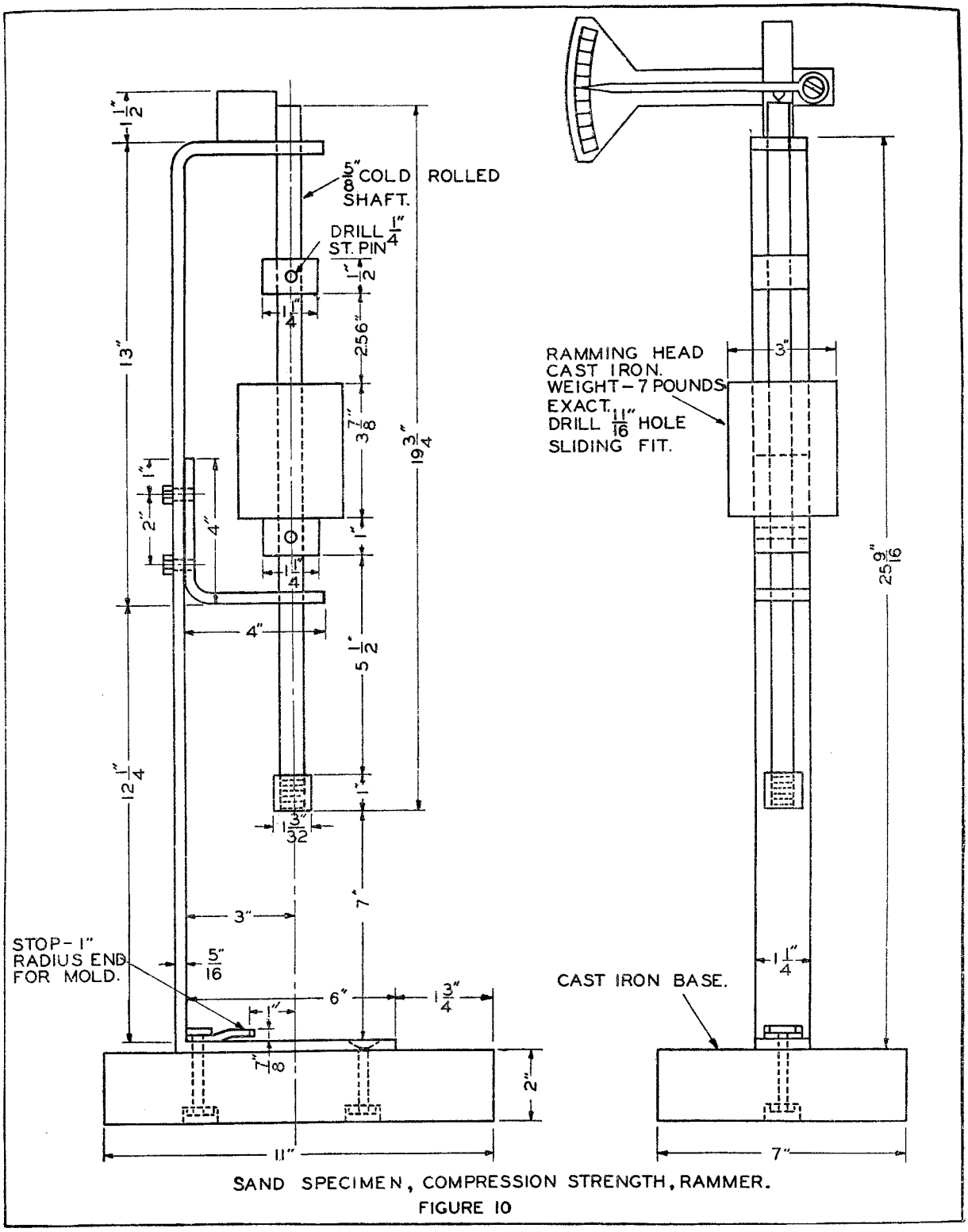


FIGURE 9

Base permeability of different sized mixtures.

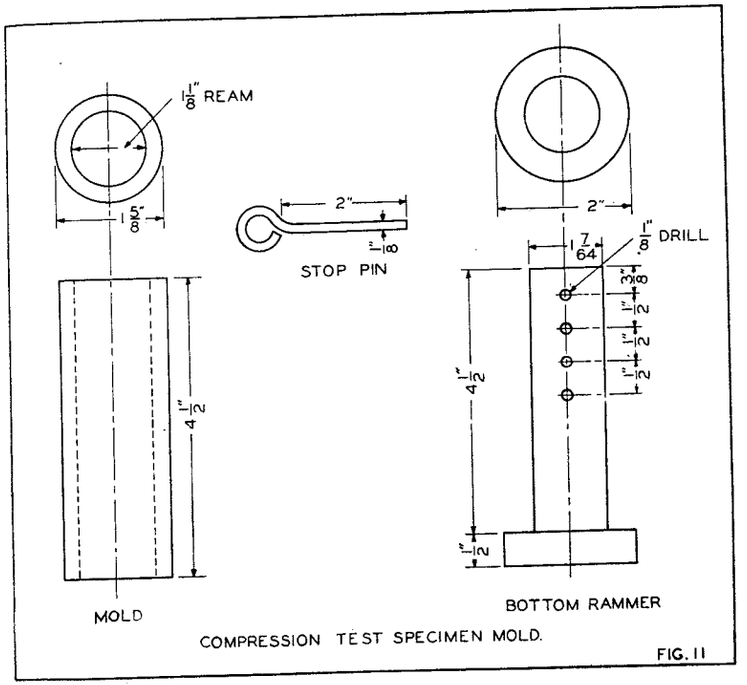


SAND SPECIMEN, COMPRESSION STRENGTH, RAMMER.
FIGURE 10

Construction of rammer for compression tests.

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 a weight is made to move out along a beam applying a load to the sample at a rate corresponding to the rate at which the weight is moved along the beam.



Construction of mold for ramming compression test specimens.

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

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

kind described. To emphasize this, it might be well to suggest that a sand composed of sand grains packed closely together as the bricks in a 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

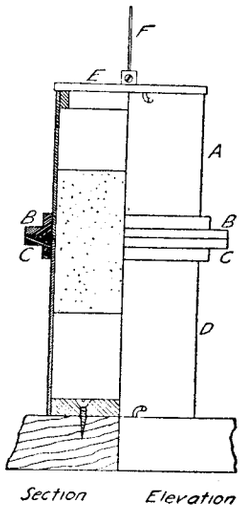


Fig. 12. Diagram of Grubb tension cylinder used to test the tensile strength of sand.

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.

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

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.

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.

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 root of the tensile, or compressive strength.

The relation between the compressive or tensile tests is not well under-

[32]Transactions of American Foundrymen's Association, Vol. 37, page 179, 1929.

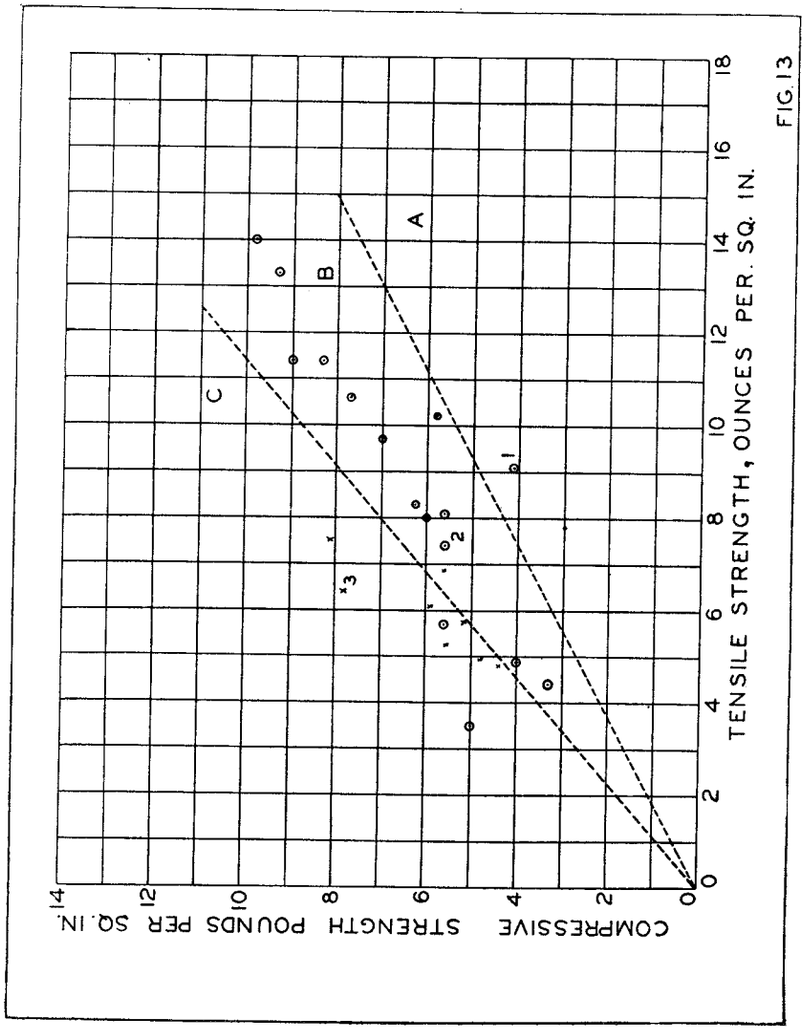


FIG. 13

Apparent relation between compressive and tensile strength of green sand.

stood, but there seems to be a rough proportionality between the two, as indicated in Figure 13.[33]

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

[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.

offers a better means of checking the strength characteristics of the heap, and consequently it was substituted for the cohesiveness of bond test as routine control check on the sand."

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.

piston rod running paralel 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 ad-

offers a better means of checking the strength characteristics of the beam

of friction clutch (H). By means of this mechanism the screw (B) propelling the weight (A) is made to stop when the sample breaks.

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

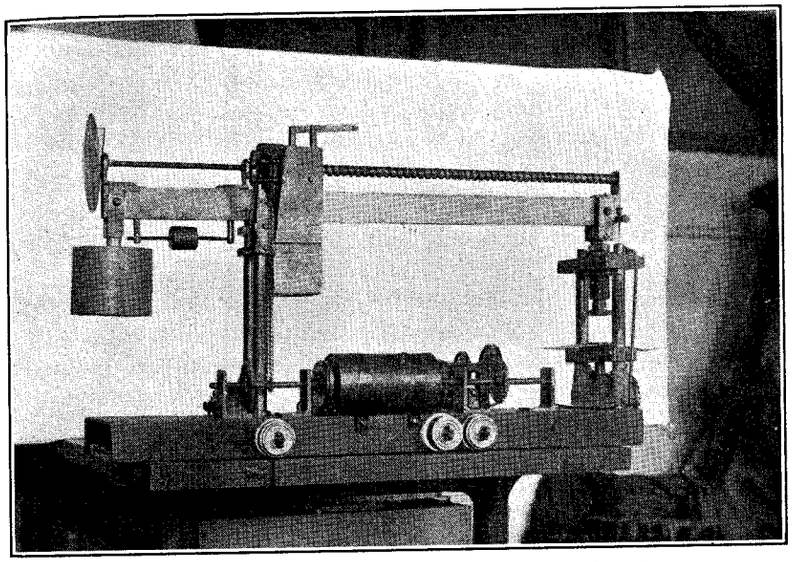


Fig. 15. Automatic machine for precision strength tests.

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 ad-

justed 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 applied 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.

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 be developed by the chain drive of the screw which propels the weight.

The traveling weight (A) is propelled by a single tooth which projects 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.

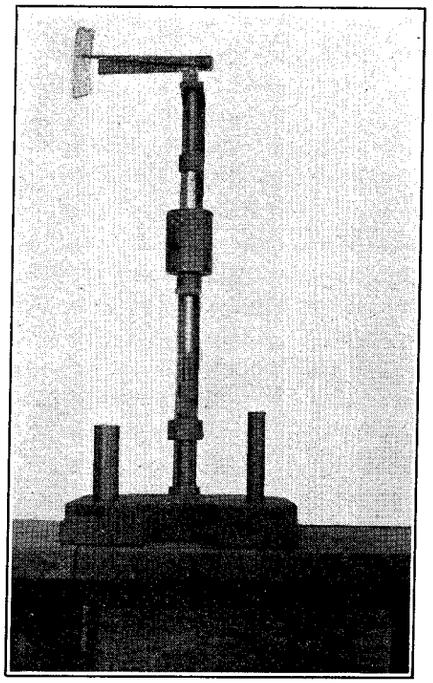


Fig. 15a. Sand rammer for compression test.

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 grams 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 may be 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.

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 pres-

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

ence 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.

[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.

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.

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.

TABLE XII.—Properties of the Natural Molding Sand.

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

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

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

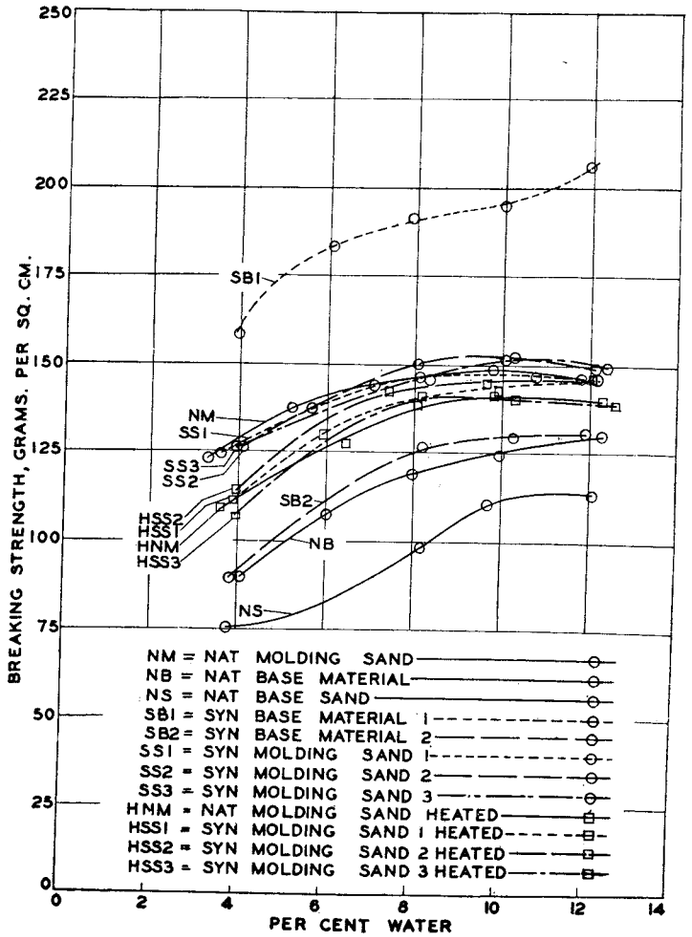


Fig. 16. Compressive strength as a function of water content.

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, ½ 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

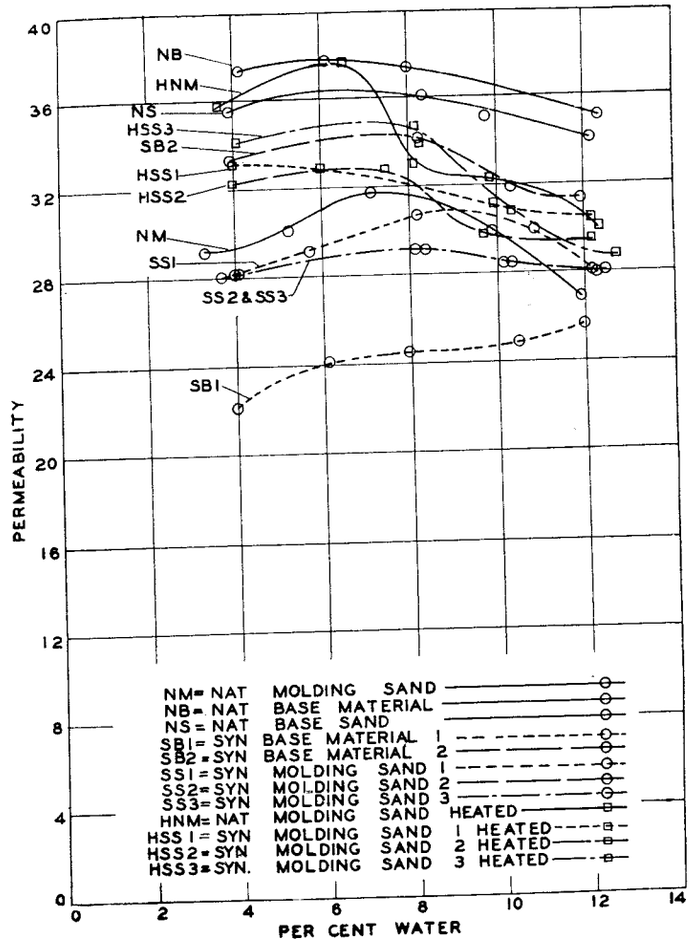


Fig. 17. Permeability as a function of water content.

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 of 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 container. 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	0.622		

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

TABLE XIII.—Properties of the Natural Base-Material.

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

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.

TABLE XIV.—The Properties of the Natural Base-Material.

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

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 to the base sand a synthetic iron hydrosol in place of the natural colloid removed, thereby forming a synthetic base-material.

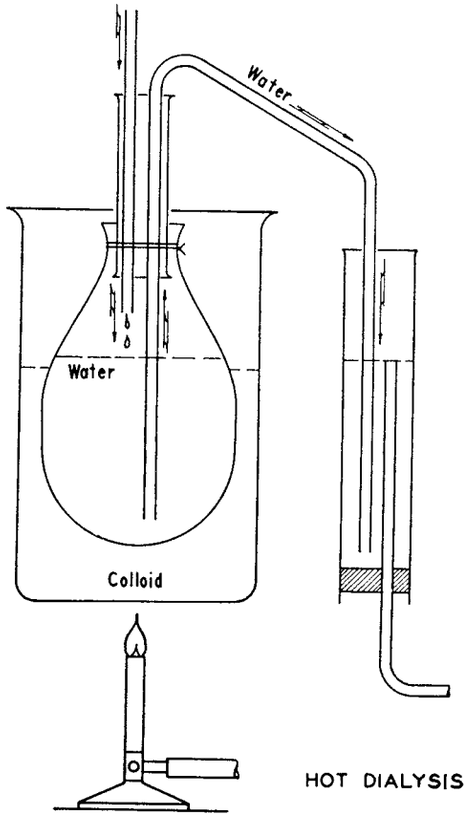


Fig. 18. Diagram showing apparatus used in dialysis.

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

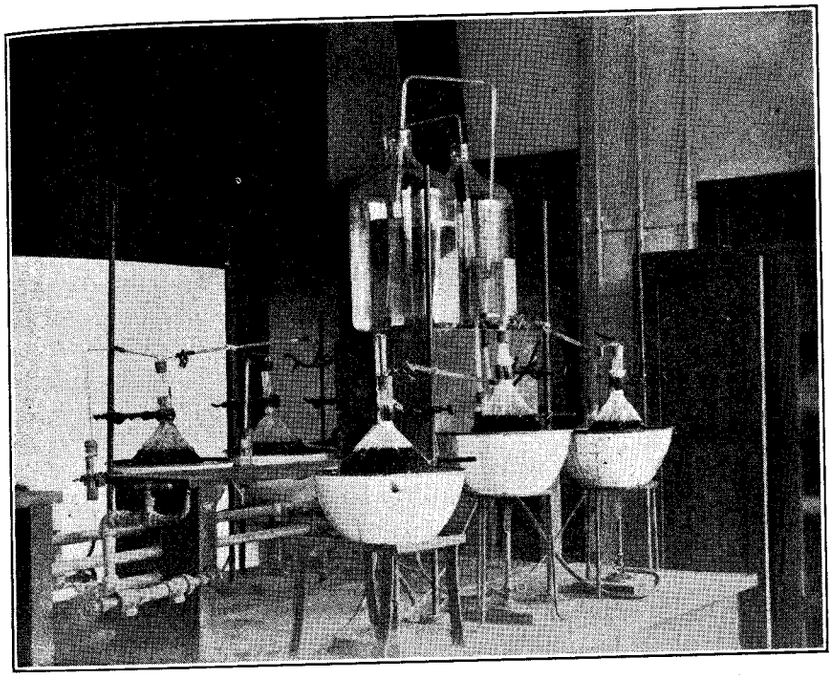


Fig. 19. Battery of three dialyzing units.

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.

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 pure 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 preparted 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 was 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. The 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 a slight stain on the enamel these pans showed no marked deterioration after one month's continuous use for this purpose. At the beginning of 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.

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 of 1 percent; for the clay the Fe_2O_3 content was 0.44 percent. The mixture 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,

[45]Jour. Am. Chem. Soc. 39, 79 (1917).
[46]Thomas—Jour. Am. Chem. Soc. *45*, 2533 (1923).

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]

TABLE XV.—Analysis of Natural Bond Material.

	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%

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'Academie Imperial des Sciences de St. Petersburg VI Ser. 31, (1909).

TABLE XVI.—Properties of Synthetic Base Material No. 1.

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

Synthetic Base-Material No. 2. The synthetic base-material No. 2 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.

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

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

The bond strength of the synthetic base material prepared from the 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.

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.

TABLE XVIII.—Properties of Synthetic Molding Sand No. 1.

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

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

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

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.

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).
Hahn, Naturwissenschaften 12, p. 1140, (1924).
Hahn, 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 thermoregulator.

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

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

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

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

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

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.

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.

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

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	32.4
7.00			
7.17	1.81	127.2	
8.0	1.902	132.9	32.4
9.0			
10.06	2.098	146.5	
10.1	1.975	138.0	
10.82	1.991	140.0	31.1
11.			
12.0	1.965	135.9	
12.9	1.885	131.7	

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.

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

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	

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.

TABLE XXVII.—Properties of Silica-Kaolin Mixture.

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	

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.

TABLE XXVIII.—Properties of Silica Base Material plus 15% Kaolin.

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	

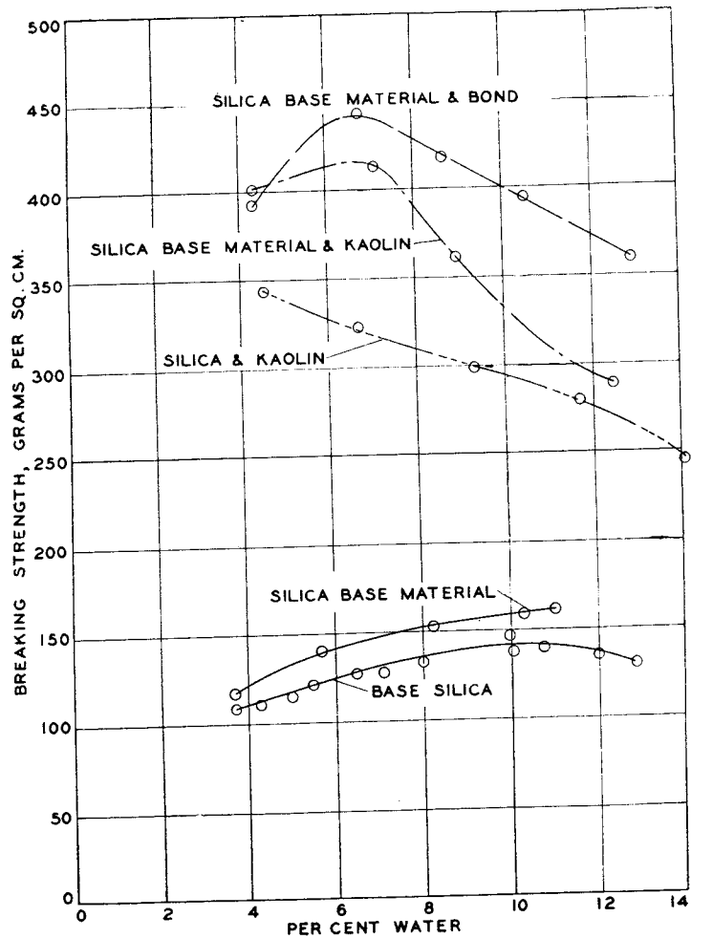


Fig. 20. Compressive strength of materials used in synthesis of bonded molding sand.

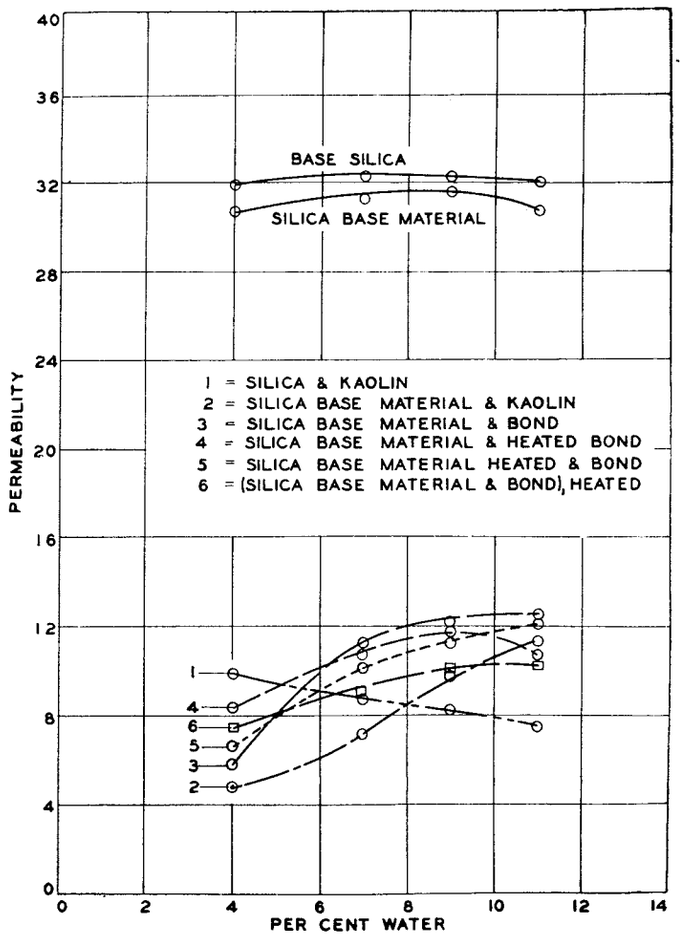


Fig. 21. Permeability of synthetic materials.

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.

TABLE XXIX.—Properties of Silica Base Material 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.	
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	

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.

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

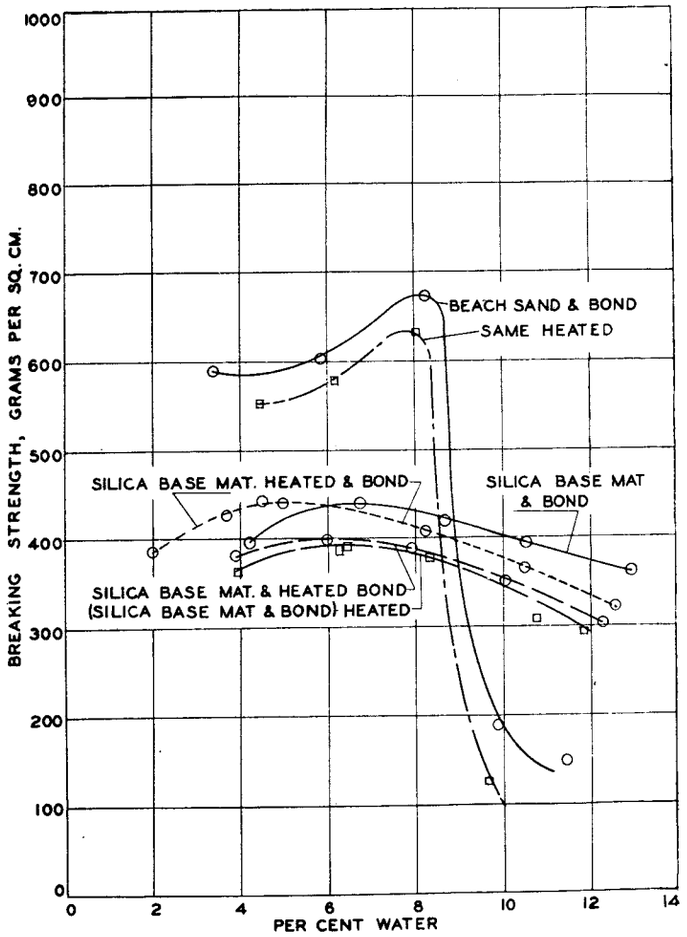


Fig. 22. The effect of heat on compressive strength of various synthetic materials.

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.

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

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

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.

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.

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

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 Hansen 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.

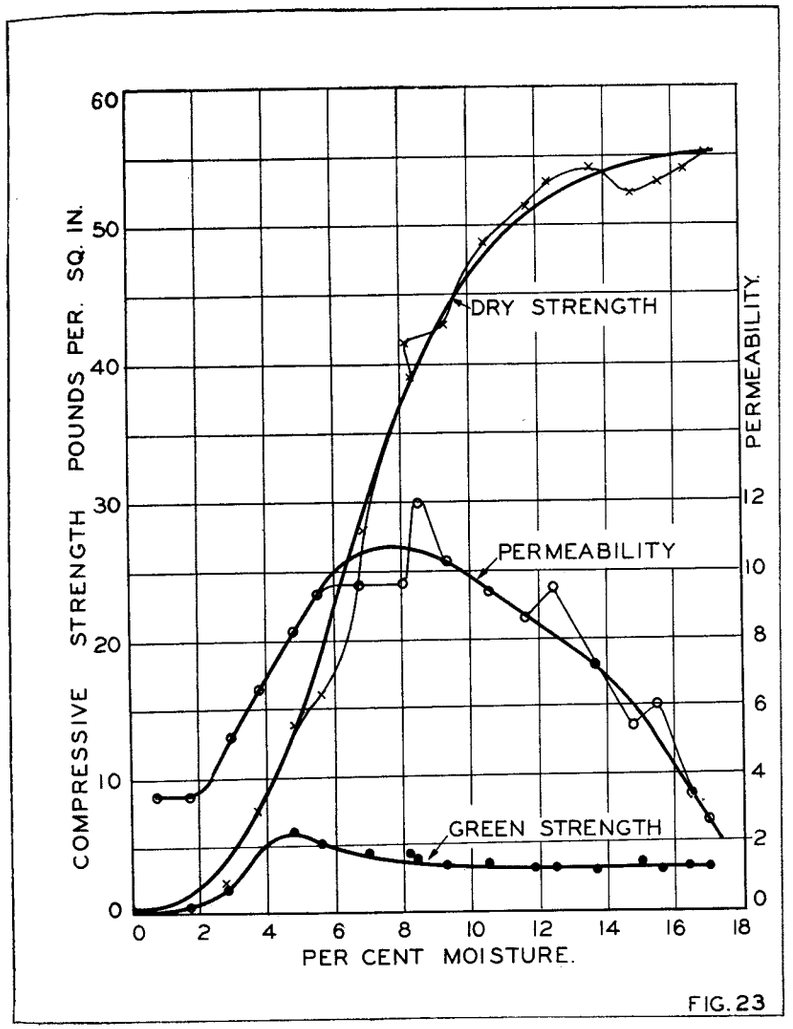
Adequate dry strength may be obtained by molding heavily clay-bonded sands at relatively low moisture content, or by molding moderately low clay-content sands at relatively high moisture. The low-clay high-moisture sands are decidedly to be preferred as being the more fool-proof. Molds may be lost in 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.

Relation Between Green Bond Strength and Dry Strength

After carefully testing the strength of the green and dry strength of a number of sands, Hansen[54] 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

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

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.



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.

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.

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 determining 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

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

substance which is accompanied by a rapid decrease in the bond strength, later 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 in permeability.

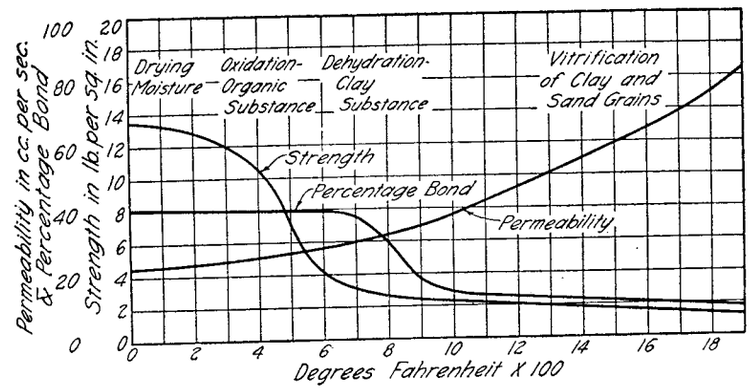


Fig. 24. Effect of heat on Zanesville sand.

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

[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.

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."

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

1	2	3	4	5	6	7	8	9
	Transverse or Cohesiveness Strength					Percent Dehydration		
Sample	10 Heats	5 Heats	Green	2 Hrs. at 600° F.	Percent Loss	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.	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.

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 may be 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 that obtained by the more complicated rehydration life factor.

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 has 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.

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.	
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	

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.

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.	
2.0	5.515	389	
3.7	6.116	430	
4.0			6.7
4.55	6.34	446	
5.0	6.274	441	
7.0			10.2
8.25	5.76	409.5	
9.0			11.3
10.55	5.21	366.2	
11.0			12.1
12.6	4.60	322.9	

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.

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

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

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 Hahn[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

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

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 as distinct from the sand or colloidal ferric hydrogel. Although the mineral kaolinite ($Al_2O_3.2\,SiO_2.2\,H_2O$) 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.

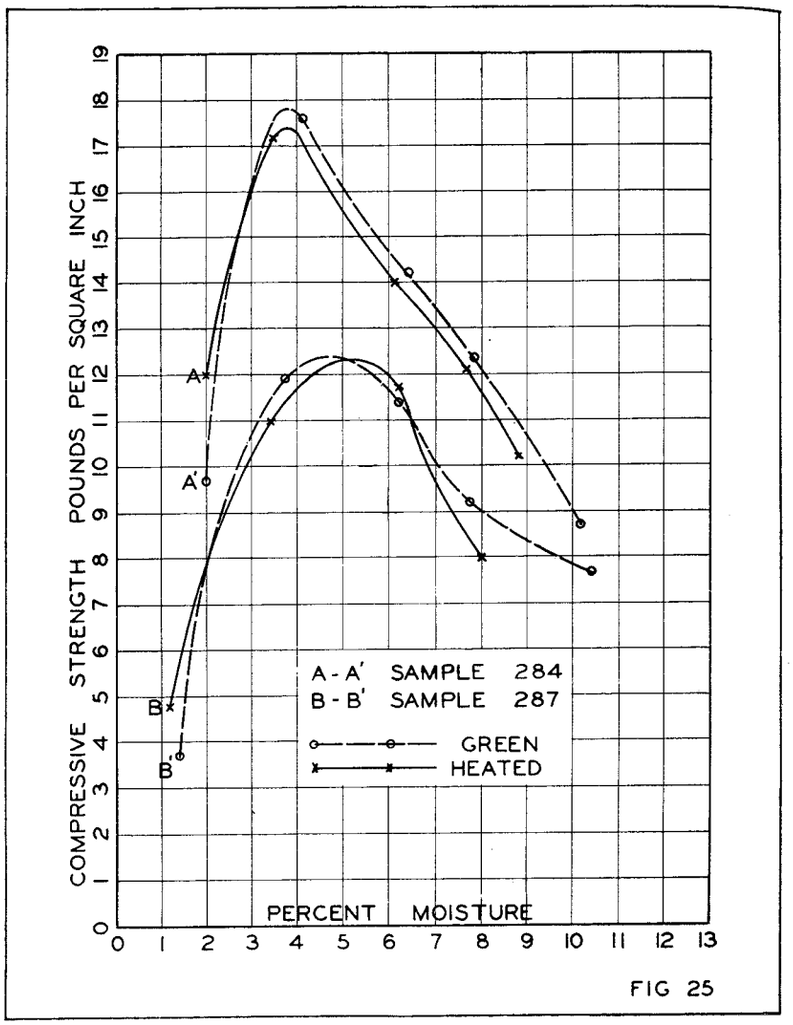
Whether or not heating may destroy other colloids than ferric hydroxide contained in the clay has not been determined as the pure kaolin used in these tests had been carefully washed and was practically free from adsorbed salts. This seems to verify the statement made by Dietert that heating the sand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

[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).

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



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

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.

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.

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

[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.