INVESTIGATION OF THE DOTY BAR TEST
FOR FOUNDRY MOLDING SAND

by

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INTRODUCTION

This investigation of the Doty green bond strength test deals with the subject of laboratory research in foundry sands. There are many characteristics in molding sands, such as clay content, grain size and moisture, which contribute to the physical properties and have a direct bearing upon the results of testing. In this study the control of the percentage of moisture has been the only variable to receive consideration as it affects the strength determination of a given sand.

Organized efforts in the matter of sand control, as it applies to foundry molding in the production of better sand castings, have been comparatively recent. Some of the early investigations were largely individual and date back to 1904. The organized work of sand testing was started in February of 1921 under the leadership of a research committee of the American Foundrymen's Association (A. F. A.) and sponsored by the American Society for Testing Materials, Canadian Department of Mines, United States Bureau of Standards, and the United States Geological Survey. Funds for the investigation were contributed to the committee by interested individuals and business concerns who foresaw the benefits that were to be derived. Progress, however, has been rapid and today many progressive foundries are equipped with sand laboratories and testing equipment for sand control.

The purpose of research in this study is to determine whether any correlation exists between the Doty bar strength and other tests that have received the consideration of the American Foundrymen's Association. At the present time, the Association recognizes only the compression strength test as a standard. The Doty bar test and the tensile test are recognized only as tentative standards and as such are suggested for comparative testing.

Investigation of published material on the subject of sand testing fails to reveal any previous effort to establish a factor of correlation in strength testing. Tests have been made involving correlations of moisture to strength; clay content and fineness of grain to strength; and between machines available for a given test. Research has also been conducted with the Doty testing machine in an effort to determine the consistency of its strength determinations for practical use.

The value of laboratory investigation of molding sand to the economic operation of the foundry has been an acknowledged fact. Therefore it was felt that if a factor of correlation in strength determinations could be established, results from all strength tests could be made standard.

ACKNOWLEDGMENT

Acknowledgment is made to Professor W. W. Carlson for his cooperation in the construction of the Doty testing and impact machine and to Professor G. A. Sellers for his assistance in the mechanical refinement of testing equipment and procedure. Appreciation is acknowledged also to the following for information and for donations of molding sand: Mr. Fred Heidon of the Victor Foundry Company, Mr. A. V. Martens of the Pekin Foundry Company, Mr. J. P. Hadank of the Peoria Foundry Company, Mr. E. B. Hazen of the Brass Foundry Company, Mr. Tom Dougherty and Mr. L. E. Roby of the Peoria Malleable Castings Company, Mr. A. J. Kirstin and Mr. L. F. Wind of the National Aluminum Manufacturing Company and to Mr. Tom McCarthy of the South Side Foundry Company.

THE DOTY BAR STRENGTH TEST

History

Origin. In testing the strength of some materials, a force factor must be applied in either of two directions, namely, in the direction of the principle axis or at right angles to it. Some investigators of molding sand have chosen the latter and the Doty test is based upon it. The test specimen in the form of a bar was pushed lengthwise over a plate until the overhanging section broke off under its own weight. The Doty test owes its conception to a sand technologist by the name of R. J. Doty who is employed by a large foundry to supervise the conditioning of foundry sands for molding. His routine work was to check twice daily the condition of the molding sand as prepared for the molder in the matter of permeability, grain size, moisture and bonded strength. The effort to devise a satisfactory strength test for conditions of molding as existed at his plant led to the development.

Development. The preliminary work to the present test was carried on in the early part of the year 1923. First, tests were made on a sand volume of 10 in. by 1 in. by 1-3/4 in. which was compressed to a bar of 10 in. by 1 in. by 1 in. The ramming was entirely from the top by means of a 3/4 inch projection on the mold box cover. The specimen was then removed from mold box and pushed off of a glass plate endwise until the overhanging section caused the bar to break. The data were secured by repeating the operation three times on each of four bars from the same sample of sand. Further refinement of the test increased the size of the bar to 12 in. by 2 in. by 1 in. and then to 16 in. by 2 in. by 1 in., the size now used.

In the preparation of the approved bar specimen, considerable difference of opinion existed as to how the bar should be formed to bring about consistent results from like conditions in sand ramming. Mold boxes with movable sides were tried, different volumes of sand were used, various methods of force were tried for the ramming operation, and still results were not entirely satisfactory. Difficulty was found in getting uniform bar sizes in different sands with an established volume by weight due to influences of clay, grain size and moisture. Suggestions were made to shave the over-thick bar to a given size and some investigators advocated the use of a mathematical factor to adjust determinations in accordance with bar thicknesses in excess of a standard.

Along with the controversy in regard to specimen size was the matter of establishing a satisfactory uniform method of ramming the sand in the mold box. Some investigators suggested the use of the molder's bench rammer and others a wooden mallet as being a convenient means for tamping.

The majority of the investigators favored the falling weight as the most suitable method for ramming the specimen. The falling weight was tried from various heights and also the number of falls were experimented with in checking results. Some of the early impact machines guided the falling weight to the mold box either inside a pipe or between two outside guides. Some permitted the weight to fall directly on the mold box cover and others added a ramming truss.

The breaking machine for the Doty tests at first was only a glass plate over the edge of which the specimen was pushed. The second stage in development was to fasten a pulling string to the paper upon which the specimen was molded, the string in turn was led over a pulley and fastened to a bucket which was weighted with sand to control the rate of specimen travel for breaking. The third stage was a motor driven spool for rolling up the paper propelling strip for breaking the specimen. A machine such as is used for the A. F. A. sponsored tests is outlined in the following chapter.

Design and Construction of Equipment

Mold Box. In the re-designing and the constructing of the new equipment for the investigation, a conscientious effort was made to eliminate all possible variables that might influence the findings and yet retain the fundamental principles as set forth for a standard Doty test.

The original mold box was constructed of wooden parts. It was felt that wood was very unsuitable material in view of the exacting limitations placed upon the finished size of the specimen. The box parts in testing are continually subjected to moisture from the wet molding sand and distortion from force of the ramming action of the falling hammer.

The mold box as used in the tests for this investigation was constructed entirely of metal, machined and fitted to the closest limits possible in keeping with the free operation of demontable parts. The mold box was further reinforced by being permanently fastened to the cast iron base of the impact machine.

Impact Machine. In previous tests conducted under A. F. A. sponorship, a sand rammer was used as shown in figure 1. The mold box was placed between the two uprights which served as guides for the falling hammer

Fig. 1. A. F. A. Impact-Hammer.

weight. The weight for ramming was hand raised by the pulling of a rope or cable over a pulley until the predetermined height of 16 inches had been reached. The rope or cable was then released from the hand and the weight dropped upon the ramming block which was placed on top of the sand in the mold box. The weight was raised and dropped two additional times from the original height, completing the ramming operation.

It was felt that considerable improvement could be made in the ramming device which would give a more reliable operation and at the same time give a more accurate fall of the hammer in conformity to the requirements as set forth in the A. F. A. recommendations (2).

In examining the illustration of the impact hammer in figure 1, it will be seen that no provision has been made for positioning or holding the rammer block or truss during the ramming operation. It is to be further observed that the release of the weight is entirely in the hands of the operator, presenting a variable through lag in manipulation.

The recommendations call for the specimen to be rammed three times by a 10 pound weight dropped from a height of 16 inches. With the machine as shown, the fall of the weight increases in height with each succeeding drop due to the tamping action of the sand. Actual tests have shown that the length of hammer fall may increase as much as three-fourths of an inch between the first and third drop.

In the design of the impact machine for this study an effort was made to eliminate the apparent faults of the previous machines and to bring about manipulation from the standpoint of convenience and to secure reliable data. Figure 3 illustrates the impact machine used in this investigation. The re-designed impact machine with an open side permits freedom for work on the mold box without the need of transfer. The hammer guide consists of a light gauge metal tube which also serves as an aligning pilot for the rammer block or truss. The guide tube also carries the release for the hammer trigger. This method of hammer release permits a uniform drop by the height stop adjusting itself to the tamping conditions of the sand. A mechanical means has been provided for raising the hammer to the predetermined height where it is automatically disengaged. It is felt that the re-designed machine provides a constant height hammer fall, free of the human factors, which often influence reliable data.

Variometer. A bar test specimen to conform to the American Foundrymen's Association recommendations must show a tolerance of not more than 1/100 inch over or under 1 inch measured at three points on each side of the test sample. The instructions require that the measurement be made with a scale having 1/100 inch graduations. This measuring process appeared very questionable and unreliable in view of the necessity of measuring to a rather indefinite rough sand edge produced in the mold box.

To eliminate the scale measurement of the specimen in determining its size, a measuring device was made which shall be called a variometer. The instrument consists of a special base and an upright to which is attached an Ames Dial Gauge No. 55 with 1/1000 inch graduations. A special large contact surface was fitted to the projecting plunger which operates the indicating hand. The variometer is calibrated to read zero with a standard 1 inch test block. For use, the instrument is placed upon the molding plate with the plunger in a raised position. The plunger is then released to rest the contact surface upon the top of the specimen just inside of the measuring edge. A reading is then made on the dial to determine the thickness of the test bar.

<u>Test Bar Breaking Machine</u>. The determination of strength in the Doty bar test is brought about by the pulling of a specimen bar of green sand 1 inch in thickness, 2 inches in width and 16 inches in length over a breaking edge at a speed of 6 inches per minute. The weight of each break is recorded and an average of all breaks is determined to give the bar strength.

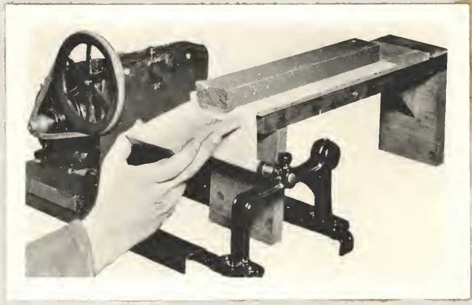

Fig. 2. Bar Breaking Machine for Doty Test

Figure 2 illustrates a machine used for breaking the bar specimens in previous tests conducted under A. F. A. tentative standards (2, p. 70). The specimen is carried forward by the waxed paper strip upon which it was formed. The paper in turn is wound upon a spool driven through gearing from a belted motor. It was felt that possible variables might exist in speed change of specimen travel due to increasing size of spool by wrapped paper which in turn accelerates specimen travel during the test.

Fig. 3. K. S. C. Impact and Bar Breaking Machine for Doty Test.

The breaking machine as designed and built for this investigation is shown in figure 3. It presents a decided compactness, embodying a gear driven lead screw. The lead screw in turn carries a nut to which is attached a clamping device to hold the waxed paper for pulling the specimen across the breaking edge of the table.

Provision was made for holding the break catch pans, thereby avoiding possible interference with normal travel of test sample. All catch pans were standardized to a uniform weight to prevent possible errors in weighing. An automatic release has been provided for the paper feed when the extreme of screw travel has been reached, thereby protecting specimen and machine through inattention on the part of the laboratory operator.

APPARATUS AND METHODS FOR TESTING

Sand Tempering

The laboratory tests were conducted upon used molding sands taken from the foundry heaps in daily use. The samples were average and sufficiently large to permit the making of all tests from a given sand.

The sample to be tested was first dried in an electric oven for an hour at a temperature between 221 and 230 degrees F. This was done to remove all moisture the sand contained from the original heap temper and to make it possible to approach a pre-determined moisture content for tests. The sand was then permitted to cool to room temperature. It was then run through a motor driven sieve shaker of number eight mesh to remove any foreign matter that may have escaped the routine foundry screening.

In the further preparation of the sand it was deemed desirable to temper a sufficient amount of a given moisture content that would permit making all tests from the same sample. Therefore, 7000 grams were weighed out of the dried riddled sand for each batch and spread upon a metal covered table in a layer about one inch in depth. The moisture increments desired were 4, 6, and 8 per cent. In the first group of tests, one-half of one per cent extra water was added to the given amount to take care of the possible loss through evaporation during mixing and handling. The water allowance was later reduced to one-fourth of one per cent as it was found that the evaporation was much less than anticipated.

For the tempering operation a small quantity of the required distilled water was sprinkled evenly over the sand. The water was then worked into the sand by vigorously rubbing the sample through the hands into a heap, taking care to eliminate all lumps. The heap was again spread into a layer and additional water added and the hand working repeated. The outlined procedure was continued until the allotted amount of water had been thoroughly distributed through the sand. The entire sample of the moistened sand was then placed in a glass container, closed with a rubber seal and allowed to temper for 24 hours in accordance with the American Foundrymen's Association recommendations (2, p. 32).

The Doty Bar Test Procedure

Forming Test Bar. All loose pieces are removed from the mold box as shown in figure 4. A piece of waxed paper for pulling the specimen is cut to length suitable to cover one surface and one-half of the underside of plate (no. 6, fig. 4). The plate is then placed in the frame (no. 1, fig. 4), the position of plate being located by lugs. Sections (no. 5, 5, fig. 4) are then replaced by moving them as far as possible toward the outer edge of frame.

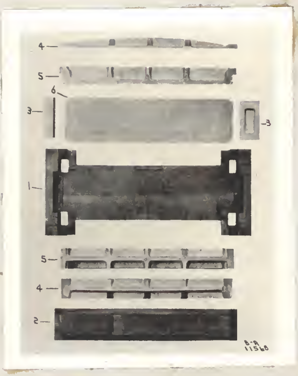

Fig. 4. Mold Box Parts for Bar Tests.

Sections (no. 3, 3, fig. 4) are then placed in position. Sand of approximately 1000 grams is needed for each test bar. The exact amount required must be determined by actual trial in view of the differences in sands to be tested. The sand is carefully transferred into the mold box with a minimum ramming effect.

The sand is then leveled in the mold box by the use of graduated strikes as shown in figure 5, until a uniform level of sand is obtained throughout the box. Care in this operation is very essential to secure constant results. After sand is leveled, sections (no. 5, 5, fig. 6) are pushed toward the center as far as possible and held in position by inserting sections (no. 4, 4, fig. 6). The trussed rammer block is then placed in a level position on the sand in the mold box. The impact hammer pilot tube is

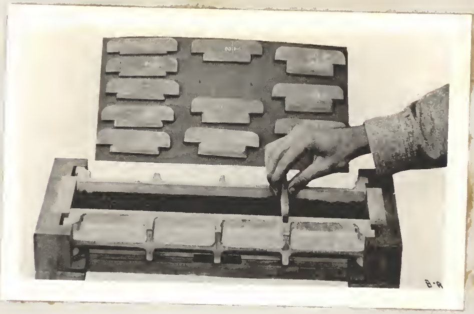

Fig. 5. Use of Strikes to Level Sand in Mold Box for Doty Test.

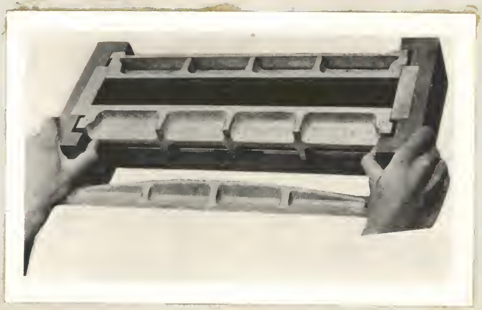

Fig. 6. Assembling Mold Box Parts for Bar Test.

then placed in locating hole in trussed rammer and the specimen is ready for the impact. It should be noted that the mold box for this investigation was made a part of the impact machine as shown in figure 3. For the ramming of the specimen, the 20 pound impact hammer was permitted to fall three times from a height of 16 inches. Upon the completion of the ramming, the trussed rammer block was removed and the mold box dis-assembled to permit removal of the specimen on the mold plate.

Procedure in Testing Specimen. The plate carrying the bar specimen and pulling paper was then placed on the table of breaking apparatus as shown in figure 3. The variometer also shown in figure 3 was then used to determine the tolerance of bar size in conformity with the A. F. A. recommendations (2, p. 72). The bar size having been ascertained, the free end of the paper was fastened to the nut which pulled the bar forward over the breaking edge of the table at a rate of six inches per minute. The weight of the overhanging section causes a portion of the bar to break off. The broken section was caught in a pan in which it was weighed. The pulling operation was continued until as many breaks were obtained as the bar would yield.

Use of Data from Test Results. The weights of all broken sections, except those which were discarded, were added and the sum was then divided by the number of breaks. This gave the average breaking weight for a bar of the thickness used. In this investigation the average was taken from 15 to 30 breaks on as many as 3 to 5 bars. The strength factor is expressed in terms of the actual weight in grams of the average break of the bar including moisture.

Permeability Test

The term permeability, as used in sand testing, is that physical property of sand which permits the passage of gases. It is upon this property of permeability that the venting qualities of sand molds and cores depend. A sand of high permeability has good venting properties because of its "openness". The degree of permeability as determined by test is found by employing a formula. By its use, permeability is ascertained as the volume of air passing per minute, per gram per square centimeter pressure, per unit volume of specimen (2, p. 41).

Fig. 7. Permeability Meter.

The test sample is a cylindrically shaped specimen 2 inches in diameter and 2 inches in length with a tolerance of 1/16 inch plus or minus. It is formed in a 5 inch length tube with the aid of the sand rammer.

The permeability meter used in the investigation is shown in figure 7. It is a product of Dietert and is of an approved type. It consists of a tank holding water, supporting an air bell to provide a sufficient volume of air pressure that is forced through the specimen in an allotted time period. In testing, the specimen in its forming tube is placed in the meter over the standardized air orifice under a mercury seal. The air valve is then opened and when the pressure between orifice and sand becomes constant a manometer reading is taken which in turn is converted into the permeability number by the use of a table.

A Dietert sand rammer as approved by the American Foundrymen's Association was used for forming the standard size test specimens for permeability, compression and tensile strength determinations. Figure 8 illustrates Dietert sand rammer.

Fig. 8. Sand Rammer.

Standard Compression Test

In making the standard compression test the same specimen as rammed for the permeability test is used after it has been stripped from its forming tube. The specimen to be tested is placed between the jaws of the holders mounted on the pendulum weight and pusher arm as shown in figure 9.

Fig. 9. Universal Sand Strength Machine.

A hand crank or motor moves the pusher arm upward through an arc, forcing the specimen to raise the weight. A scale carrying a magnetized rider gives a reading in pounds per square inch required to break the specimen. The machine used is made by Dietert and is of an approved type.

Tensile Strength Test

The tensile strength test is made by applying a load uniformily along the axis of the cylindrical test specimen 2 inches in diameter and 2 inches high. The tensile strength determination is obtained from the average of at least three tests and the results are expressed in pounds per square inch of cross-sectional area.

The apparatus used in this investigation is illustrated in figure 10 and was made by Dietert. The test specimen is of the same size as for the permeability and compression test, but is formed in a special two-piece mold that is used in connection with the testing. The regular sand rammer is used for compacting the specimen.

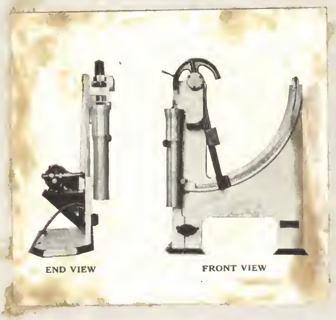

Fig. 10. Tensile Sand Strength Machine.

In testing, the mounted specimen is clamped to the vertical pulling unit of the testing machine. A yoke is fastened to the top of the specimen which in turn is connected to a weight arm that is raised through an arc by the pull on the specimen. The maximum swing of the arm is then recorded by a dog that is engaged on a rack. The recording arm is then freed and permitted to return to a balanced position where a reading is again made. The difference between the readings gives the actual tensile strength of a given sand.

Clay Determination

The procedure for the determination of clay content or bonding substance in a given molding sand was carried out in accordance with the A. F. A. standard procedure (2, p. 90). Fifty grams of dried molding sand are put in a quart fruit jar with 25 cubic centimeters of a standard solution of sodium hydroxide and 475 cubic centimeters of distilled water. The jar is then placed in a sand washing machine as pictured in figure 11 where it is churned at 60 revolutions per minute for one hour. This machine was developed and built in the Kansas State College engineering shops. It consists of a motor driven rotator holding six one quart fruit jars.

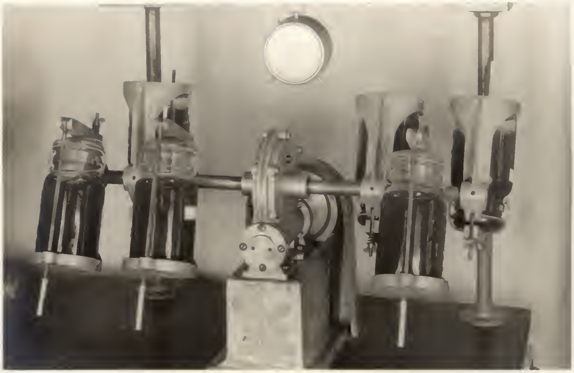

Fig. 11. K. S. C. Sand Washing Machine.

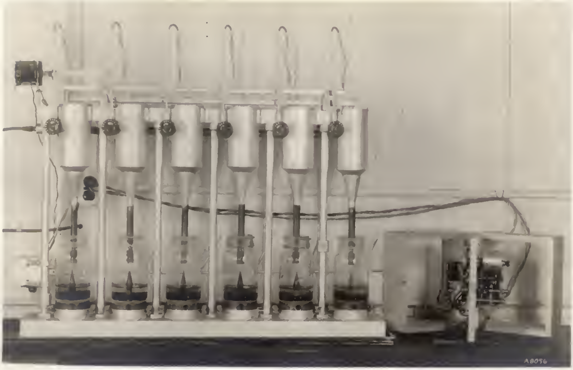

Fig. 12. K. S. C. Clay Separating Machine.

After the sand is washed, it is transferred to the glass jars of the clay separator which automatically controls by electric relays, the American Foundrymen's Association timed intervals for separation and flushing for the removal of clay content (2, p. 91). The apparatus shown in figure 12 was used in this investigation and is a development of Professor G. A. Sellers of Kansas State College. It was constructed in the Kansas State College engineering shops and is part of the sand laboratory equipment.

The clay free sand is then dried by the standard method and re-weighed (2, p. 92). The difference in weight from the original 50 grams, multiplied by the factor of 2 gives the clay content in percentage. In this investigation, three samples of each given sand were tested for verification in results. Figure 14 gives percentages of clay as found in the sands tested.

Fineness Test

The fineness of a sand refers to the size distribution of the grains. In general, for testing purposes, the particles may be divided into two groups, the larger ones representing sand and the finer ones being termed "clay".

The fineness of a foundry sand affects the permeability, strength, amount of moisture required for mixing, and the surface of the casting. The object of a fineness test is to determine the percentage of the different sizes of sand grains and the amounts of clay which the sand contains.

The fineness tests for this investigation were made upon a given sand from which the clay had been previously washed during the clay determination. The dried sand was put into the top of a group of United States Bureau of Standard numbered sieves as shown in figure 13 and as specified for testing by the American Foundrymen's Association (2, p. 88).

The sieves are known as half-height and have a diameter of eight inches. The coarsest sieve is placed on top and the finest at the bottom of the group. A cover is placed on top and pan on the bottom to collect what passes through the finest sieve. The sieve assembly was then placed in a sieve shaker and the specimen shaken for fifteen minutes. The amount of sand remaining on each sieve is carefully weighed and expressed in percentage of the original weight of 50 grams. The portion passing the last sieve is known as pan material and is so noted.

Fig. 13. Sand Testing Sieves.

Moisture Content

The actual moisture content of the sand sample under test was determined by weighing out 100 grams at various intervals during the testing period of a given sand. Usually one of the broken sections from each bar test was retained for a sample and an additional amount was taken from that remaining in the supply jar after all tests were completed.

After weighing, the sample was heated for one hour in a controlled temperature between 221 and 230 degrees F. and then permitted to cool under glass cover to room temperature. The difference between the dried sample and the original 100 grams gave the moisture content in per cent.

Mulling Machine

The machine available for mulling and mixing sand as needed for tests was made by the Clearfield Machine Co., Clearfield, Pennsylvania and known as the Clearfield Laboratory Mixer.

Drying Oven

For the drying of sand samples and for the determination of moisture content, a specially reconstructed baking oven was used. The oven capacity had an inside dimension of 14 in. by 14 in. by 18 in. The temperature to conform to the American Foundrymen's Association standard was maintained by electric heating elements regulated by a Brown Controller, thus providing uniform temperature for all tests.

Scales

The weighing involved in the determinations of moisture, clay content, and breaking strength from Doty test was done on a one pound capacity Torsion Balance reading by hundredths grams. The scale was glass screened to prevent influences of air currents upon readings.

COLLECTION OF SAND AND FOUNDRY DATA

The molding sands used in the investigation were collected from seven foundries operating in the industrial area of Peoria, Illinois. All the foundries were using natural sands obtained from v arious locations.

Another foundry in the Peoria area was found to be using a synthetic sand, bonded and controlled by daily laboratory investigations. In view of the number of foundries using the natural sands, it was decided to limit the investigation to natural bonded sands as found in the working heaps and supply bins. Samples were obtained from three distinct types of foundries, namely, non-ferrous, gray iron and malleable iron.

A total of twenty samples were obtained. No effort was made to retain moisture contents in the sand as found, the intention being to control the moisture at the time of tests. The sand was placed in closely woven sacks, labeled as to its class and district, and then enclosed in metal containers for shipment to the Kansas State College.

The collection of sand samples gave an opportunity to secure information on present conditions in the use of sand control, how far laboratory practice enters into present day foundry work, and the attitude of the foundry operators toward scientific conditioning of molding sand. As previously stated, one shop using synthetic sand was equipped with laboratory facilities for control.

The group using natural sands were entirely without any means of accurate analysis. The tempering and conditioning of the sand for molding work was determined by the time honored practice of hand feel, gained through experience of years of work with given sands.

An amusing side light upon the use of psychology along with molding sand was gleamed from one foundry foreman. The foreman, upon being asked as to what district the sand he was using came from, replied, "Sandusky, Sandusky, Illinois". In explanation, he stated that he was using Sandusky sand in name only in order to satisfy the molder's demand for one that they were used to; an Illinois sand, because it was cheaper, just as good for the work, and more economical to use.

The interviewed group of foundrymen, as a whole, saw the need at times for scientific control. They seemed interested to learn of its benefits and the results of past investigations. Some of them, at different times, had been in attendance at the annual convention of the American Foundrymen's Association. However, none of the group had any definite plant plans for the establishment of a sand laboratory in connection with the foundry procedure.

SUMMATION OF PHYSICAL TESTS

The curves and tables submitted indicate, in graphic and tabular form, certain trends in strength determinations of the sands tested. General characteristics of all sands tested are recorded in figure 14. The strength trends of a given sand may be analyzed by examining the data for the contributing factors in their effect upon the strength performance. Figure 15 indicates the rise and fall in the strength of a sand as influenced by the differences in clay content and moisture. Figure 16 graphically protrays the relationships between strength tests of sands based on moisture content. A permeability curve for comparison of sands of a given moisture percentage is superimposed upon the strength curve to show relationships between permeability and strength. Figure 14 gives tabulated information on each sand tested and by consulting the data, one may determine the influences the various physical properties have upon the factor of strength.

Sand Lab. No.		On 6	On 12	On 20	On 30	On 40	On 50	On 70	On 100	On 140	On 200	On 270	In Pan	Avg. Clay Content - Grams	Avg. Clay Content - Per cent	Moisture in Per cent	Average Permeability	Average Compression	Avg. Tensile Strength	Doty Bar Avg. Strength	Kind of Sand
10	%	0	.20	.64	.72	2.96	5.24	11.08	11.36	8.56	17.72	13.60	19.20								Albany, N.Y. Medium-Iron
	Gr.	0	.10	.32	.36	1.48	2.62	5.54	5.68	4.28	8.86	6.80	9.60	4.26	8.77	4.76	19.6	4.17	69.6	130.4	
11		Sand Classification: Fineness No.				Grain Class No.				Clay Class						7.39	19.8	4.22	84.	127.7	
12		126				3				D						9.08	19.2	4.14	84.2	128.6	
20	%	0	.04	.28	.36	1.24	2.32	3.88	5.48	7.28	17.08	11.64	32.08								Gem - Canton, O. Aluminum
	Gr.	0	.02	.14	.18	.62	1.16	1.94	2.74	3.64	8.54	5.82	16.04	8.60	16.99	6.26	7.4	7.47	147.6	168.7	
21		Sand Classification: Fineness No.				Grain Class No.				Clay Class						7.08	7.7	7.30	139.2	165.1	
22		175				2				E						8.95	7.0	7.51	147.6	166.8	
30	%	0	.68	1.24	1.32	7.0	8.32	9.40	9.04	8.56	16.08	10.44	19.64								Evansville, Ind. Medium Iron
	Gr.	0	.34	.62	.66	3.5	4.16	4.70	4.52	4.28	8.04	5.22	9.82	4.26	8.41	4.15	9.9	5.17	49.	131.8	
31		Sand Classification: Fineness No.				Grain Class No.				Clay Class						6.06	15.5	5.76	83.7	138.7	
32		136				3				D						7.59	15.7	5.60	87.5	141.4	
40	%	0	.44	1.72	1.52	4.76	10.64	15.16	15.36	9.44	9.56	4.32	12.84								Grade 4 M. Evansville Medium-Iron
	Gr.	0	.22	.86	.76	2.38	5.32	7.58	7.68	4.72	4.78	2.16	6.42	6.26	12.79	4.92	17.7	6.1	51.	135.8	
41		Sand Classification: Fineness No.				Grain Class No.				Clay Class						6.62	27.	6.0	55.	140.	
42		96				2				E						8.0	37.	5.6	58.	134.5	

Fig. 14 - Summary of Sand Characteristics.

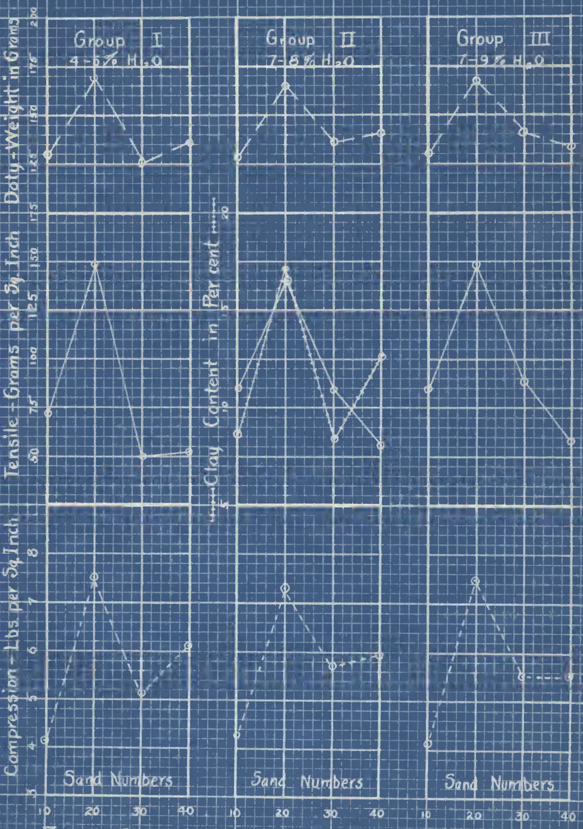

Fig. 15- Strength Curves by Sands with Clay Content.

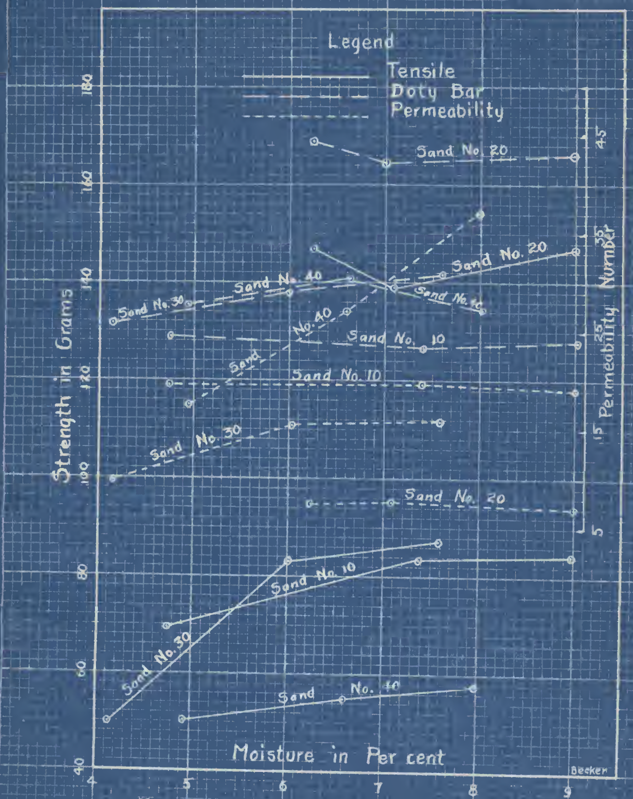

Fig. 16 - Tensile and Doty Bar Strength Comparison with Permeability.

CONCLUSION

In view of the time limitations placed upon this study, the data secured from the investigation are far too insufficient to establish a factor of correlation between strength tests.

The experience gained by this investigation has shown that the Doty method of cohesive testing, when properly standardized by suitable equipment, is an excellent one for comparative work. It must be said, however, that a certain amount of experience is necessary, on the part of the investigator, to gain uniform results in view of the manipulative details involved in forming the test specimen.

The Doty bar test equipment, as developed for this investigation, functioned very satisfactorily. Further improvements in the breaking machine might be made in the lengthening of the table to permit the breaking of an entire bar without the shifting of the paper pulling nut. A ball bearing slide on the pulling nut guide would also add to the smoothness of operation by the elimination of friction in the present bronze bearing.

It is regretted that the investigation did not reach the objective as planned for at the time of undertaking the study and it is hoped that others interested in furthering the study of sand control will carry on and reveal definitely what the author has only indicated.

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