May 5, 1953 W. H. MOORE 2,637,212

OPTIMUM TEMPER MOISTURE DETERMINATION IN FOUNDRY SAND

Filed July 14, 1950 2 SHEETS—SHEET 1

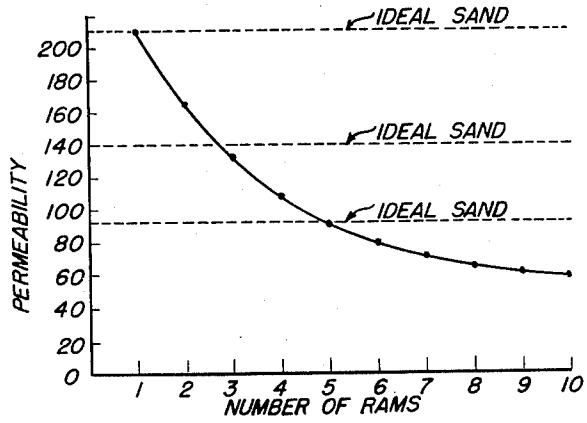


Fig. 1

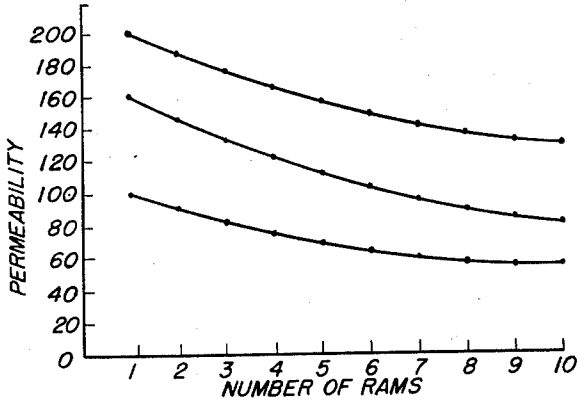


Fig. 2

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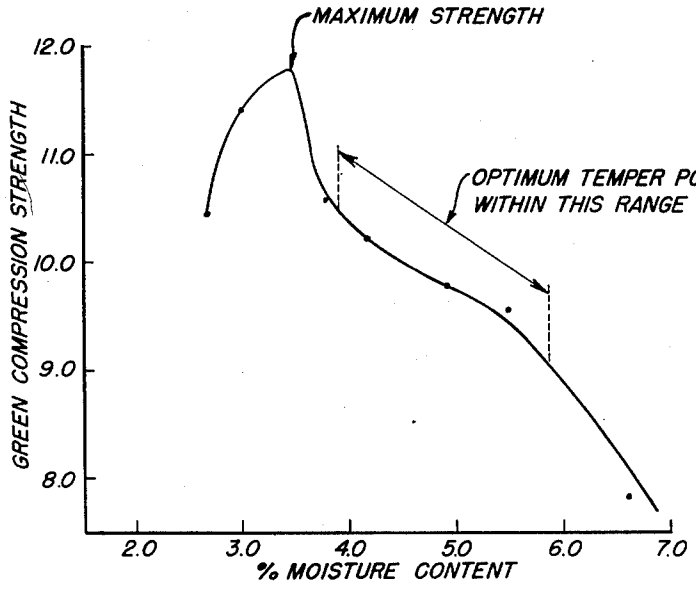


Fig.3

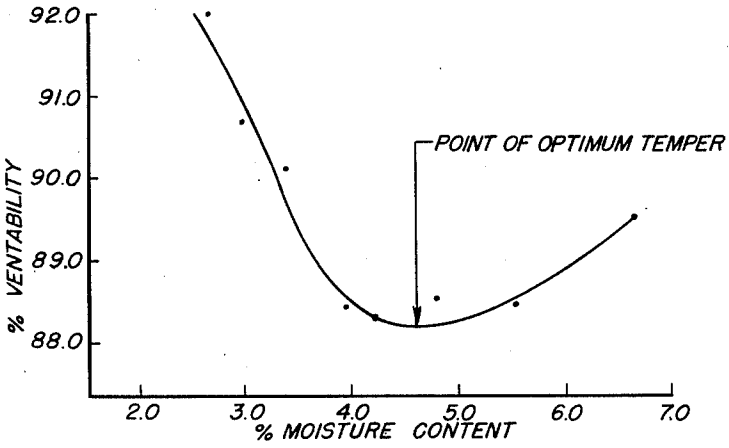


Fig. 4

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Patented May 5, 1953

2,637,212

UNITED STATES PATENT OFFICE

2,637,212

OPTIMUM TEMPER MOISTURE DETERMINATION IN FOUNDRY SAND

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Application July 14, 1950, Serial No. 173,852

1 Claim. (Cl. 73—432)

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This invention relates generally to foundry sand practice, and more specifically to a method of evaluating the optimum temper value of a foundry sand mix.

The object of this invention is to provide an accurate dependable means to measure the optimum moisture content necessary to insure the best workability in any given sand mix.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawings, in which:

Figure 1 is a curve plotted from one given sand by testing the permeability over a variation in ramming;

Figure 2 is a curve of several sands, plotted as in Figure 1, but each sand having different beginning and ending permeabilities at various levels;

Figure 3 is a curve plotted from one given sand illustrating the change in green strength with respect to increase of moisture content; and

Figure 4 is a curve plotted from one given sand produced by determining the degree of change of permeability at varying moisture contents, and illustrating the leveling of the resultant curve at the point of optimum temper.

The preparation of a mold for casting metal has long been subject to many variables, particularly those variables due to uneven ramming or packing of the sand around the pattern. Thus in ramming by hand, for example, certain areas of the mold will always be rammed harder than other areas, and the resultant molds have not been uniform in their behavior towards the molten metal that is subsequently introduced into them. Where the ramming is soft, the mold surface will be weak and porous, and the appearance of the casting at this point will be rough and uneven. When the ramming is hard the casting may contain defects due to the inability of the metal to lie quietly on a hard surface of high density.

The introduction of mechanical methods of ramming molds has done little to improve this situation, as the uniformity of ram is very largely dependent on the design of the mold cavity and the molding sand is unable to pack firmly in narrow pockets and the like. In the past, with a skillful hand ram it was possible to carefully pack the sand in these narrow pockets and thereby present a mold of fairly uniform properties. However, this peening operation requires more than average skill on the part of the operator and is time-consuming, so it has little place in the modern methods of manufacture.

This problem of obtaining a uniform mold surface by the ramming of sand has been given considerable attention in the past, but with little

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success. One such means has been to use a hardness tester on the molds in order to investigate the relative hardness at any particular spot in the mold. If this hardness was adjudged to be too low, then the ramming was increased. However, an increase in ramming increases the hardness at the spot under discussion and also increases the hardness at other portions of the mold. This method therefore does not improve the uniformity of hardness over the mold surface. The hardness can be raised and lowered by alteration in the degree of ramming, but the different hardness values in different areas of the mold cannot be substantially avoided.

In order to make a commercially salable casting free from blemishes and defects, a mold surface must have two very definite properties at a suitable level. It must have strength and rigidity to resist the fluid pressure of the molten metal, and it must have permeability to dissipate steam and other gases. Too low a strength will lead to collapse of the mold surface, and too high a strength may cause contraction strains and even cracks in the casting. Too high a permeability will give a rough, uneven surface to the casting, and too low a permeability will lead to blows, scabs and many other common casting defects.

It has been generally recognized that the permeability and the strength of a molding sand will vary according to the degree to which the sand is rammed, and according to the type and amount of bonding agent, as well as the amount of actual temper moisture present. Thus, as we ram harder we will increase the strength and decrease the permeability. It had not heretofore been realized, however, that the amount of change in these properties with ramming is capable of measurement and control in such a manner that a uniformly hard mold may be produced regardless of the degree and method of ramming employed.

My copending application entitled "Foundry Sand Control," filed concurrently herewith, teaches in detail the effect of change in permeability, called ventability, and the effect of change in strength, called bondability. The teachings of that invention are useful alone, but one more factor could, and should, be integrated along with the control available by following the teachings of that invention.

I have discovered that both the change in degree of permeability over a range of ramming, or ventability, and the change in degree of strength over a range of ramming, or bondability, are related to the temper moisture.

A sand that would not change in permeability, or strength, whether rammed a slight amount, or much, could be termed an ideal sand. This term should not be construed to mean that any sand

which did not change with ramming, would be suitable for all mold sizes. It means only that no change is experienced. The permeability and strength values could be too high, or too low, for a given problem, in some particular ideal sand. Of course, if such an ideal sand were available at the proper permeability and strength levels, then the ideal sand would truly be ideal for the job.

Of course, an ideal sand is only a theoretical substance not available even in laboratory quantities. But an ideal standard is useful for foundrymen to use as a tool in compounding an actual sand for foundry use.

Grain size and shape play a large part in ventability and bondability. If every sand grain were a uniform sphere, then no amount of ramming would pack the grains tighter once they contacted one another. With pure sand alone, since there would be no change with ramming, a ventability of 100 per cent would result.

If now we included with these uniform diameter spherical grains sufficient uniform small size grains to fill in the spaces between the larger spheres, we would have an entirely different condition. Here, no matter how long we jolted or agitated the grains, we would probably never assume the exact mathematical arrangement which would give the closest packing of the grains and therefore a constant amount of void space between the grains. As long as the sand grains cannot be readily packed together in their closest arrangement, we will always have some variation in void space and in ventability over the whole surface occupied by the grains. We would in fact have a low ventability—low from the standpoint of uniformity .

Bondability, which is the change of strength of a sand over a range of ramming, is affected by the temper moisture in the bond. An ideal sand would be one that would give the greatest strength uniformity over the mold surface with the minimum degree of ramming. Going back to the conception of equal size rounded grains, it is necessary to imagine each grain surrounded with a uniformly thick layer of bonding material which we will consider as the clay bond.

The most acceptable theory of clay as a binding material postulates alternate layers of clay flakes and water flakes, the exact arrangement depending on the clay type involved. Thus, three types of bond structure may be distinguished.

1. *Montmorillonite group and secondary mica group.*—In the water film between two flakes water dipoles are interposed between the surface cations and the surfaces of the flakes. Assuming water dipoles arranged in layers, these layers will carry a positive charge on one face and a negative charge on the other. As quartz has a negative surface charge, the structure of the water film between a clay flake and the quartz grain resembles that of the water film between two clay flakes. However, there are not so many cations as these are derived from the clay flakes alone. Thus, the intensity of the electrostatic field between the quartz grain and a clay flake is not as high as that between two clay flakes. Consequently, clay flakes are not held so tightly to quartz grains as to each other.

2. *Kaolin group.*—Here the flakes are held together by secondary attractive forces between the hydroxyl sheet of one unit and the oxygen sheet of the next. Here the structure of the film between a clay flake and a quartz grain will be similar to that between two flakes.

3. *Limonite group.*—Cleavage of limonite materials into flakes does not occur as readily as in clay materials. As the limonite materials have a positive charge and the quartz has a negative charge, there will be an intense electrostatic field between the two, and they will be tightly held together.

As these clay bonds vary somewhat in their structure, we would expect some effect on bondability according to whether the clay flakes are strongly attracted to the grains and to each other, or according to whether they are loosely attracted and will not interfere with the movement of the sand grains.

As also the binding force is electrostatic in nature, the closer the approach between the grains and the flakes, the stronger and the more uniform will be the bond. Thus, hard ramming and close packing will result in high and uniform bonding. The degree of ability to pack closely will be determined by the character of the clay bond and the number of water films associated with the clay bond.

Thus, the greater the number of water films, the more their tendency to leave an ordered electrostatic arrangement and form a random arrangement where the films will act as a lubricant and affect the friction between the grains during the packing or ramming operation.

The bond may exert a considerable influence on ventability and bondability. Only by considering both can we arrive at an understanding of the different workability found in sands during the ramming operation.

It is necessary always to bear in mind that clay arranged around the silica grains and excess clay in lump form which does not move integrally with each grain are quite different. Thus, excess clay not adequately distributed by mulling around the silica grain will act as a void filler. The net result will be a loss in ventability or uniformity of permeability at the mould face. If, however, the clay moves as an integral part of each grain, there will be little effect on ventability beyond slowing the flow action by virtue of friction or increasing the flow action by lubrication—this depending on the amount of water associated with the clay.

In order that the term ventability, meaning the degree of permeability over a range of ramming, is fully understood, and capable of measurement by one skilled in the art, one method of calculation and measurement, and a series of graphs produced by measuring various sands will be considered.

Laboratory measurements of permeability involve preparation of a standard sample two inches in diameter and two inches high. This sample is rammed three times by dropping a weight of 14 pounds through a height of two inches on the sand. This is a standard ram, and it has long been realized that this standard degree of ramming used in the laboratory is not fully representative of the average degree of ramming used in the foundry. Each method of ramming in the foundry is either lesser or greater than the standard ram, depending on whether the ramming is a hand operation, a jolt operation, a jolt-squeeze operation, or a slinger operation.

As the result of a long experience in the different methods of ramming and in the art of producing foundry molds and cores, I have been able to establish a ramming range in the laboratory manner which will adequately represent the degree of ramming obtained with normal methods

of ramming used in production. Thus, if I ram a sand in the laboratory at one ram or one drop of the weight as a minimum, and ten rams or ten drops of the weight as a maximum, I will have conditions representing and including the softest and the hardest rams usually found in practice.

I do not wish to limit myself strictly to this range of ramming. I have chosen this range of ramming as being representative of the average range found in practice, but the method of testing which I will describe hereafter can just as easily be applied to a degree of ramming considerably wider than this one-to-ten ram range. Thus, I could use a range of one-to-two rams or one-to-100 rams in order to include some unusual method of ramming in practice. I could also change the 14-pound weight used to any other value, and I could prepare the samples by different methods of ramming. The standard method of sample preparation has been chosen as a basis of measurement merely because of convenience. In the same way, the range of one-to-ten rams on the standard rammer has been chosen merely because it is reasonably representative and includes most normal degrees of ramming or hardness found in practice.

Reference to Figure 1 shows a graph which records the test conducted on a molding sand. The lowering of permeability can be observed from this graph as the ramming increases. On the same graph the broken lines represent theoretically ideal sands which retain their properties at the same level throughout the ramming range. These ideal sands are shown at different levels of property values to emphasize that the only requisite of an ideal sand is no change in properties with ramming.

It matters little whether these properties are at a high level or at a low level insofar as designating it as an ideal sand. Ideal simply means that there would be no change in green strength or permeability, regardless of the number of rams. One particular ideal sand may not be a suitable sand for a given mold, although it could be. If the ideal level falls at a strength that is too high or too low, or at a permeability level which is too high or too low, or both, then a good casting will not result, regardless of the fact that the sand is an ideal sand and does not change its characteristics with additional ramming.

It should be emphasized that progressive ram tests are by no means new and have been conducted by many sand technicians in an effort to differentiate between the behavior of various sands. However, the tests are always at an arbitrary standard, not related to actual foundry practice. Further, and by far the greatest failure, these tests stand alone as academic facts, unrelated in any way to actual foundry practice. It is a well-known fact, until the time of this invention, that laboratory test data on sand is of little practical value, and that usually the foundry foreman will alter his sand by some hunch or guess, often based upon reasoning amounting almost to superstition.

Figure 2 illustrates a fact which was heretofore apparent, but which was never used in a process of selecting and blending a satisfactory mold sand with the proper optimum temper point, as this invention now teaches. Figure 2 is a chart showing several curves resulting from plotting permeability changes with respect to the number of rams in a standard controlled laboratory test. In each sand the permeability of the sand decreases with increasing ramming. This fact is expected, and is explainable by the foregoing discussion concerning the comparison of perfectly spherical sand grains to a mixture of sand grain sizes and shapes. Bonding material, and the effect of the temper moisture upon the bonding material and sand, are further factors affecting permeability, but in any event a given sand will produce a test curve, or any sand may be compounded and altered to produce a variety of curves.

From Figure 2, the fact is apparent that not any degree of permeability can be obtained from one sand. Some sands, however, give a much wider span of values, resulting in a graph more like Figure 1.

One may conclude that the logical solution to the production of a desired permeability would be to control the ramming. But that solution is not satisfactory, especially in view of the human elements involved. Adjustment of the average sand grain size and type, bonding material, as well as adjustment and control of the moisture to obtain the optimum moisture content, is the better solution of the problem of permeability. An approach to an ideal sand is desirable, but the more nearly a sand mix approaches an ideal condition, the less range of permeability it includes; therefore, the less universal in application it becomes. Accordingly, there is both a theoretical and practical limit in the approach toward the theoretical perfect permeability.

We can now proceed to actually express and measure the ventability of any molding or core sand simply by reference to an ideal sand. Consider, for example, the test given in Figure 1. At the first ram the sand has the permeability of 210 (arbitrary scale). If it would show the same value of 210 over the complete ramming range, then it has no degree of change, and is said to have 100 per cent ventability. If now this ideal condition is set down in tabular form and each permeability value divided by the succeeding one, we will have the following:

Permeability

No. of Rams	Permeability	Sub-Total
1	210	$\frac{P \text{ at } R1}{P \text{ at } R2} = \frac{210}{210} = 1.00$
2	210	$\frac{P \text{ at } R2}{P \text{ at } R3} = \frac{210}{210} = 1.00$
3	210	$\frac{P \text{ at } R3}{P \text{ at } R4} = \frac{210}{210} = 1.00$
4	210	$\frac{P \text{ at } R4}{P \text{ at } R5} = \frac{210}{210} = 1.00$
5	210	$\frac{P \text{ at } R5}{P \text{ at } R6} = \frac{210}{210} = 1.00$
6	210	$\frac{P \text{ at } R6}{P \text{ at } R7} = \frac{210}{210} = 1.00$
7	210	$\frac{P \text{ at } R7}{P \text{ at } R8} = \frac{210}{210} = 1.00$
8	210	$\frac{P \text{ at } R8}{P \text{ at } R9} = \frac{210}{210} = 1.00$
9	210	$\frac{P \text{ at } R9}{P \text{ at } R10} = \frac{210}{210} = 1.00$
10	210	Total.... 9.00

Where: P=permeability; R=ram number.

In this ideal case the total of the quotients equals 9.00 which is said to be 100 per cent ventability. It must be remembered that there is no

significance in the value of 9.00 apart from the illustration given.

If now we set down in tabular form the actual results obtained with sand depicted in Figure 1 we have the following:

Permeability

No. of Rams	Permeability	Sub-Total
1	210	$\frac{\text{P at R1}}{\text{P at R2}}=\frac{210}{160}=1.31$
2	160	$\frac{\text{P at R2}}{\text{P at R3}}=\frac{160}{130}=1.23$
3	130	$\frac{\text{P at R3}}{\text{P at R4}}=\frac{130}{106}=1.22$
4	106	$\frac{\text{P at R4}}{\text{P at R5}}=\frac{106}{90}=1.18$
5	90	$\frac{\text{P at R5}}{\text{P at R6}}=\frac{90}{78}=1.16$
6	78	$\frac{\text{P at R6}}{\text{P at R7}}=\frac{78}{70}=1.11$
7	70	$\frac{\text{P at R7}}{\text{P at R8}}=\frac{70}{62}=1.13$
8	62	$\frac{\text{P at R8}}{\text{P at R9}}=\frac{62}{60}=1.03$
9	60	$\frac{\text{P at R9}}{\text{P at R10}}=\frac{60}{58}=1.04$
10	58	
		Total 10.41

Where: P=permeability; R=ram number.

These totals are now substituted into the following formula:

$$\text{Percentage of ventability}=\frac{9.0-(\text{Total}-9)\times 100}{9.00}$$

or

$$\text{Percentage of ventability}=(18.0-10.41)\times 11.11$$
$$=84.24\%$$

It has now been demonstrated how the change in properties with change in ramming of a sand may readily be related to a theoretically ideal condition. The mathematics of this method are not of importance, for on certain sands it will be found that the changes in properties with ramming are an exact logarithmatic function and the same relationship to the ideal condition may be expressed by the use of logarithms. Also, as previously explained, the ramming range may be changed to suit any condition.

It has long been realized that any sand mix in a foundry has a definite moisture content where it possesses the optimum properties. Excess moisture beyond this point and insufficient moisture below this point seriously detract from the workability of the sand mix. This optimum temper point for any sand mix has been very difficult to evaluate accurately and the nearest approach has been to determine the change in strength with moisture content as depicted in Figure 3.

The correct temper point is usually taken as falling anywhere from ½ to 2½ per cent higher in moisture than the point of maximum strength. In other words, it is recognized that at the peak strength point, the sand is in a definitely brittle condition and is under-tempered. Using a moisture content in practice at a somewhat higher value than at the peak point gives a tougher sand and allows a strength increase with drying out rather than a strength decrease as would be the case if the sand were worked at very near the peak value.

Unfortunately, such a broad range of moisture is not permissible in practice because as it may be appreciated the properties of the sand may vary quite considerably over such a range. I have discovered, as shown in Figure 4, that the optimum temper point may be established quite accurately by using the ventability relationship. If we plot the ventability against the moisture content for the same sand we will notice a valley or trough in the curve. The point of lowest ventability is the true optimum temper point for the sand mix. Anyone skilled in the art of sand testing and sand control will readily appreciate the importance of this discovery.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

I claim:

The process of determining optimum temper value of a sand mix comprising the steps of, providing a sand mix, taking a plurality of separate samples of said sand mix, ramming a sample of said sand mix with a series of ramming strokes, testing said sample after various intervals of ramming for permeability to thereby determine the degree of change of said permeability with progressive ramming, altering the moisture content of a second sample from the moisture content of the first tested sample and determining the degree of change of permeability during progressive ramming, continuing testing of said plurality of samples in like manner each with a different moisture content, and selecting the moisture content of the sand mix which displays the least amount of change upon altering the moisture content thereof to the next increment of moisture content as indicating the optimum temper value for the particular sand mix tested.

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Dietert, "Foundry Core Practice," pages 194–196, 422 and 423.