HOT PROPERTIES OF MOLDING SAND

INTRODUCTION

When the surface of a mold fails, the casting produced from it will be characterized by one of these: cut, wash, erosion, scab, rattle, buckle or scab. These casting losses are linked to the elevated temperature properties of sands and may be predicted, and therefore controlled, through high temperature testing.

In order to identify and prevent casting losses, the foundryman must have some understanding of the mechanisms causing the scrap. Unfortunately, there are many unknowns, but there is some general agreement regarding the causes for rejects. It might be well therefore to present briefly the theories in common acceptance.

When molten metal enters the mold cavity, a number of resultant forces tend to destroy the mold. They include hot gases produced in heating the mold, expansion of the sand grains and the work done on the mold by the flowing metal itself.

When metal flows into a mold cavity, its turbulence and its shearing action against the mold walls tend to scour the mold surface and tear the sand grains from one another. Wherever the intergranular bond fails, and the grains are displaced, there will be a void in the smooth mold face and a resultant imperfection in the casting requiring additional cleaning effort. This type of scrap will generally appear where the metal has the highest velocity, especially where there is a "nozzle" effect.

This scrap is due to erosion and can often be identified by its location and by the presence of sand imbedded in the casting at some other point downstream, or above the original void. Cuts, washes, and erosion, or type "B" scabs fall in this group.

By virtue of its kinetic energy and static pressure the molten metal also tends to deform the mold mechanically and to change the dimensions of the cavity. This will, of course, affect the weight and size of the finished casting. This growth or distortion is seldom considered as a surface failure but since much of the mold deformation occurs in the cool subsurface sand, the proper approach to this problem lies in room temperature testing.

The destructive effects caused by the temperature of the molten metal are especially serious, as many of the common casting losses are due to the instability of the sand mix at higher temperatures. Heat produces a breakdown or an alteration in the binders and promotes expansion of the sand grains. This expansion may produce internal stresses too great for the rammed sand mass to withstand, and the mold surface will fail.

Failure can occur in a number of forms such as rattle, buckles or scabs. The relationship between these failures is illustrated in Fig. 13.115.

In eliminating scrap, the foundryman must reduce the magnitude of the disruptive forces, or increase the magnitude of the restraining forces. In any event, the foundryman must be able to measure the basic properties and high temperature reaction of the sand as a guide to proper control.
same tests should also be of value in predicting losses so that the foundryman can take corrective measures before the sand becomes an immediate problem.

A number of tests have been developed that measure the ability of a sand to withstand compressive loading at high temperatures, the magnitude of the expansion at various temperatures and the amount of deformation that a sand will undergo before collapse.

**EQUIPMENT**

To measure the properties of foundry sands at elevated temperatures the foundry laboratory should be equipped with a number of specialized instruments. The basic unit should be a high temperature furnace with a loading system capable of breaking the sand specimens in compression at any temperature up to the pouring temperature. Suitable equipment should also be provided for measuring hot deformation and expansion.

Figure 13.116 shows one type of basic test instrument commercially available for high temperature testing. This unit is a furnace having a range from room temperature to 3000 °F. It is equipped with a sensitive temperature controller and the furnace is constructed so that the hot zone is accessible from the side or from below.

This model has a hydraulic loading system capable of applying a compressive load as high as 5000 psi on a 1-inch diameter specimen. The load is applied hydraulically but measured mechanically for maximum accuracy. Through a simple adjustment of the mechanical linkage, the range can be varied from 0 to 100 or 0 to 1000 psi.

The hot deformation, or movement under load at elevated temperatures, may be measured with an indicator or a recorder attached to the furnace. Figure 13.117 shows a hot deformation recorder as it would be mounted on a test furnace for high temperature testing. Deformation of the sand specimen and the load applied are each measured as a change in the position of the core of a differential transformer.

Free and confined expansion tests can be made through the use of a unit like the expansion micrometer shown in Fig. 13.118. This instrument consists of a quartz frame equipped with a quartz stem dial indicator. The specimen to be tested is inserted in one end of the frame with quartz discs at each end, and a quartz rod is slipped between the specimen and the dial indicator. The end of the micrometer frame is inserted into the test furnace chamber through the horizontal port and the change in length of the specimen is read from the dial indicator.
The elevated temperature tests are conducted in a furnace heated by a number of silicon carbide elements. The specimens are brought to temperature by radiant heat from the hot furnace walls and from the elements themselves. With this method of high temperature testing, the rammed sand specimen absorbs heat in the same manner as it would on the face of a mold or core. The outer layer in the furnace and in the mold is heated from the surface inward.

The correlation between casting surface scrap and high temperature test data indicate that the radiant heating method parallels the conditions found in a mold. The atmosphere surrounding a mold or core surface will affect the hot properties of a sand, particularly that of a core bonded with an organic binder which will burn readily. A hooded post is recommended for the testing of all cores containing organic binders in order to prevent rapid oxidation of the core binder.

The hood, as shown in the section on veining, traps the gases given off by the sand specimen and the specimen is therefore treated in an atmosphere of its own gases. This simulates mold conditions closely with the exception of the gases from the molten metal, but these will be much smaller in volume than gases produced by the mold, or core surface.

EXPANSION

The expansion of molding sand may be determined under two methods of heating. Much of the data found in literature refer to the expansion of materials under slow heating of the test specimen. This is frequently referred to as dilations. Another method which is favored more for molding materials is shock heating.

In the case of slow heating, a temperature rise of 10 °F per minute is often employed. The specimen is inserted in a cold furnace. For shock heating, the furnace is heated to, for example, 1800 °F, and the specimen inserted into it. The shock heating expansion is greater than slow heating expansion.

Various materials have different expansion values, silica-base sands having the greatest. In a decreasing order of shock expansion silica, olivine, mullite, chamotte, zircon and coke, are illustrated in Fig. 13.119.

In addition to the two methods of heating the specimen, namely, slow and shock, one has to consider three more conditions of the test specimen. The conditions of specimen that are in use may be defined as free, confined and loaded. When the test specimen is free to expand in all directions, it is spoken of as free expansion, either slow or shock heated. The sand specimen may be rammed within a quartz or carbon tube, and the expansion test made in this condition is referred to as confined expansion under slow or shock heating.

A third condition that has good practical application is the loaded expansion where the specimen is placed under a load, for example, of 1 psi. This test is usually made under shock heating and is termed shock loaded expansion. It does not employ the expansion meter shown in Fig. 13.118 as the other expansion tests do. The shock loaded expansion test employs a simple durable setup as shown in Fig. 13.120.

The dilatometer furnace is set up as for strength determination with top stationary post and a movable bottom post. The movement of the bottom post is shown on a dial indicator set under the dirt pan of the bottom post assembly. The bottom post is loaded with hydraulic pressure from a hand oil pump.

The furnace is heated to 1800 °F. A specimen rammed to a hardness as used in the foundry is inserted between the posts within a 15 sec time interval. A one psi load is applied to the specimen by means of a manual oil pump which may be equipped with a dilatometer.
RAMMING

Sand specimens used in elevated temperature testing are usually the 1 1/8 x 2 in. size. The hardness to which these specimens are rammed is either the standard hardness obtained with three drops of a 7 lb weight, falling 22 1/4 in., or the foundry hardness to which the sand is rammed in the molds.

The foundry hardness method is the proper one to use when one wishes to make a direct correlation between elevated temperature test values and casting quality. The test specimens may be readily rammed to the chosen foundry hardness when the sand rammer is equipped with an adjustable ramming device as shown in Fig. 13.121.

The standard hardness method may be used to determine the hot properties of molding materials under standard conditions of constant ramming energy. It is well to show the specimen green hardness with the test data.

SPALLING

The standard 1 1/8 x 2 in. specimen is a good one for the visual spalling test. The specimen may be rammed to the standard hardness, or better, to a hardness equaling that used in the foundry. The specimen is inserted into the dilatometer furnace at 2500 F in either the green, dried or baked state, depending on how the sand is used in the foundry.

The cracking or spalling of the specimen is observed through the observation port at time intervals of one and 2 min, and the approximate total length in inches of cracks observed at each time interval is recorded. Photographs may also be employed as a record, in which case, the photograph is made immediately after the specimen is removed from the furnace (Fig. 13.122).

HOT STRENGTH

The hot strength of molding sands is made on the 1 1/8 x 2 in. specimen (double end ramming) either with standard or foundry hardness. The test data should show the hardness of ramming employed.

Practical test temperatures for hot strength are 500, 1000, 1500, 2000 and 2500 F. The time the test specimen soaks in the furnace is usually 12 min, after which time, the specimen is loaded at a standard rate. The loading rate as set with a ceramic specimen is from 30 to 730 psi in 15 sec.

The magnitude of the hot strength varies according to type of bond, grain size, moisture, additives, degree of ramming, atmosphere and degree of spalling. In practice the hot strength is usually controlled by the selection of bond, fines and additives.

A few examples are given to illustrate foundry practice. Maximum hot strength is obtained for large steel or iron castings by mixes of fireclay and western bentonite plus an addition of silica flour. Medium hot strength is secured by using a mixture of western bentonite, southern bentonite and an addition of cellulose material. Low hot strength is secured for castings that hot tear easily by a mix bonded with southern bentonite plus cellulose material.

Figure 13.123 is a graphical representation of how hot strength of a 4 per cent western bentonite bonded
sand is affected by additions of scowal, wood flour and cereal. All of these additives reduce the hot strength. The hot strength of 4 per cent southern bentonite bonded sand is also shown in Fig. 13.123.

The grain fineness of a sand will markedly affect the hot strength. The graph in Fig. 13.124 shows the hot strength of various sands composed of different grain sizes, bonded with 4 per cent western bentonite.

Neglecting the 2000 F temperature, which softens most of the bonds and some of the sand grains, one can make this statement — the smaller the grain size the higher the hot strength for temperatures between 500 and 2000 F inclusive.

The hardness to which a mold is rammed will greatly change the hot strength of the sand. This is well illustrated in Fig. 13.125, where the hot strength increases at all temperatures as the squeeze pressure (psi) is increased.

**HOT DEFORMATION**

The hot deformation of a molding sand is obtained at the same time that hot strength is determined. A recording hot deformation unit (Fig. 13.117) or an indicating deformation accessory may be used. The hot deformation is expressed in inches of specimen shortening per linear inch. Thus a high hot deformation value describes a sand that has a high degree of hot plasticity. A sand of this nature will accommodate a large expansion without mold wall fracture.

The control of hot deformation needs much more study by foundrymen in order to put this hot property of a sand to good use. It must be recognized that hot deformation may be expressed as the ultimate or as a rate. The ultimate deformation at rupture load at present knowledge does not yield much practical information. A factor that lends itself to practical application is the hot deformation rate.

The hot deformation rate is computed by determining the deformation at some relatively low load, for example, 50 psi.

Formula: Hot deformation rate = \( \frac{\text{Hot deformation at predetermined load} \times 10000}{\text{predetermined load}} \)
The graphs in Fig. 13.126 show the hot deformation rate at various temperatures of different bonded sands.

The hot deformation rate at 2000°F is tabulated in Table 13.23 for a 4 per cent western bentonite bonded sand with various additives. The order of hot deformation rate from low to high is: 15 per cent silica flour, no additive, 2 per cent wood flour, 1 per cent cereal, 3 per cent pitch, and 5 per cent seacoal. Additive materials such as cellulose, cereal, pitch, and seacoal increase the hot deformation rate, allowing the sand to accommodate all, or a portion, of the expansion. Thus, combustible additives reduce mold wall fracture which is scrap producing.

Moisture to which a sand is tempered also affects the magnitude of the hot deformation rate. In order to demonstrate this, select a western bentonite bonded sand, mix one batch to low moisture, one to temper and another to high moisture. Determine the hot strength and hot deformation at 2000°F under standard ramming. Using a recording deformation accessory one will obtain stress-strain diagrams as shown in Fig. 13.127.

In order to study these graphs from a hot deformation rate viewpoint, first determine hot deformation at 50 psi. This 50 psi load is shown by a dotted line in Fig. 13.127. The hot deformation at 50 psi load is:

The sand at high moisture has a 50 psi hot deformation of 0.011 in and a hot deformation rate of 0.22. The sand at temper has a 50 psi hot deformation of 0.021 in and 0.012 hot deformation rate. The sand at low moisture has a 50 psi hot deformation of 0.035 in and hot deformation rate of 0.70.

Thus a sand mixed to a high moisture will have a low hot deformation. It has a low ability to accommodate any grain growth due to expansion. A sand tempered to the dry side of temper will have more hot deformation and thus have less tendency to scab, buckle or rattle than a sand tempered to high moisture.

<table>
<thead>
<tr>
<th>Additive</th>
<th>Deformation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Silica flour</td>
<td>0.064</td>
</tr>
<tr>
<td>No additive</td>
<td>0.158</td>
</tr>
<tr>
<td>2 Wood flour</td>
<td>0.226</td>
</tr>
<tr>
<td>3 Cereal</td>
<td>0.332</td>
</tr>
<tr>
<td>3 Pitch [27]</td>
<td>0.380</td>
</tr>
<tr>
<td>5 Seacoal</td>
<td>0.650</td>
</tr>
</tbody>
</table>

Fig. 13.126 — Curves showing effect of additives on hot deformation at 50 psi load.
Fig. 13.127 — Curves showing how hot deformation is affected by moisture.

**HOT SAND TOUGHNESS**

The product of ultimate hot strength and ultimate hot deformation times 1000 gives a factor termed 'hot sand toughness'. It may be used to express the amount of punishment a mold wall will take in reference to toughness. Figure 13.128 gives a graphical presentation of the hot toughness of various bonds at various temperatures.

The hot toughness of the various bonds at 2000 F, from low to high order is 4 per cent southern bentonite, 4 per cent western bentonite, 12 per cent fireclay, 1.75 per cent of western bentonite with 1.75 per cent of southern bentonite plus 3.50 per cent fireclay. The blend of bentonites and fireclay giving the toughest sand mix. This is found to be true in practice where a blend of bentonites and fireclay is employed for heavy castings.

**SCAB SCRAP**

Scrap caused by scabs should be classified as being of two types, the erosion scab and the expansion scab. The erosion scab is an area of the casting where sand and metal are mixed, while in the expansion scab, a thin piece of metal is separated from the body of the casting by a layer of sand, which may not be present after the casting is cleaned. An expansion-type scab is illustrated in Fig. 13.129.

The control of erosion scabs solely by dry compressive strength testing is dangerous as this test does not give an accurate indication of the bond at high temperatures. Figure 13.130 illustrates the variation in hot compressive strength that may occur between sands having the same dry strength. Each binder is affected differently by temperature, and while a number of mixers may have the same green or dry properties, the strength of each may vary at high temperatures through change in the condition of the binder.

During the pouring operation, the walls of the mold cavity are brought to a high temperature quickly, but due to the insulating properties of the sand, there will be a large thermal gradient across the first layers of sand. The surface layer will increase in temperature at a greater rate than the sand immediately behind it.

Fig. 13.128 — Hot sand toughness of sand containing different bonds.
The hot silica grains will expand rapidly and build up great compressive stresses in this thin layer, if the grains cannot rearrange themselves to relieve the stresses. If there is no relief, the surface layer will rupture. One form of rupture produces the expansion, or type "A" scab. This scab is characterized by protruding edges, raised above the casting surface and separated from it by a layer of displaced sand, as shown in Fig. 13.129. This type of scab may be pried or chipped off, leaving a depression in the casting surface.

The AFS Committees 8-1* and 8-1** have developed two simple tests to measure the scabbing tendencies of molding sands. A test that lends itself well to both iron and steel sands is the restraining load test. The dilatometer is setup as if for hot strength tests, with the exception that a dial indicator or a hot deformation recorder is used to measure any movement of the bottom post.

A schematic diagram of the dilatometer setup for this test is shown in Fig. 13.131. A dial indicator as shown in the sketch is adjusted to measure any movement of the lower post. This indicator or a recording hot deformation unit will show any change in length of the test specimen.

The purpose of the test is to apply sufficient load to the sand specimen to restrain the expansion, thus holding the sand specimen to a constant length and bringing into play hot deformation to accommodate the expansion of the sand. Amount of load required to produce sufficient accommodating hot deformation varies with different sands.

Those sands that require low loads to produce sufficient hot deformation to cancel out any expansion will be free of mold wall fractures. Conversely, those sands requiring high loads to produce sufficient hot deformation to cancel out the expansion of the sand will have more and longer mold wall fractures.

For iron molding sands the duration of the test is 5 min during which time the load on the specimen is constantly being changed manually by means of a hydraulic pump. The dial indicator or hot deformation recorder is held at zero (indicating constant specimen length, ±0.001) by adjusting the load applied.

At a 5 min interval the operator records the load in psi that is required to hold the specimen at a constant length. The relationship between the 5 min restraining load and total length of scabs, raitails and buckles for the ten castings made during a meeting of the 8-1 Committee is shown in Fig. 13.132.

The test data for 10 sands fall close to a line which shows that increasing mold wall fractures occur with an increase of the 5 min restraining load. This test has practical application for measuring the scabbing, raitailing and buckling tendencies of iron molding sands.

For steel molding sands, the restraining load is recorded at 5 min intervals. An average of ten 5 min restraining load test values may be used to determine whether a sand will scab or will not scab using 50 psi load as the dividing line. Sand with a restraining load above 50 psi will scab on most molds.

A second scab indicating test is the shock load expansion test, and is based on a study of test data by AFS Committee 8-1. The study covered ten different

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*Physical Properties of Iron Foundry Molding Materials at Elevated Temperatures Committee.
**Physical Properties of Steel Foundry Sands at Elevated Temperatures Committee.
sands which were used to cast gray iron test castings under closely controlled conditions. Their results indicated that shock load expansion test data may be used to predict whether a sand will cause a mold fracture defect such as a ratail or scab on a gray iron casting.

The magnitude of the scrap may also be predicted for a given sand condition. The furnace of the dilatometer is held at 1800°F for the shock load expansion test. The dilatometer is set up as if for hot strength, but with a dial indicator under the (dirt) pan to measure movement of the bottom post. A one-pdr. load is placed on the sand specimen and expansion is read from dial indicator after 25±sec. of heating.

The greater the shock expansion, expressed in inches of expansion per linear inch of specimen, the greater the total length of defect. A graphical presentation of the correlation is shown in Fig. 13.133. It should be noted that an exceptionally good correlation exists. Sands with a shock load expansion less than 0.003 are easy to mold free of mold fracture scrap.

RATTAIL AND BUCKLES

Rattails shown in Fig. 13.134, and buckles shown in Fig. 13.135, are expansion type scrap that are subject to close control through high temperature testing.

The AFS Committee 8.1 found good correlation between rat-tail scrap and a hot compressive strength coefficient expansion relationship. A sand showing a high coefficient expansion at 2500°F and a high hot compressive strength at 1000°F will tend to produce rat-tails or buckles.

Figure 13.136 shows the relationship between these properties and rat-tail scrap in gray iron castings made with the rat-tail pattern developed by AFS Committee 8.1. This pattern produces castings in the form of a plate 11 in. long, 9 in. wide and 1/2 in. thick.

Figure 13.135 may be used as a rough reference for applications similar to the rat-tail casting. The sand can be tested for hot compressive strength at 1000°F and continued expansion at 2500°F and the value plotted on this graph to determine whether or not the sand has rat-tail tendencies.

If the test data fall close to the line dividing the rat-tail and non-rat-tail zones, the sand mix should be considered as subject to scrap and the composition should be changed to improve the mix.

The hot compressive strength test for rat-tails is run in a test furnace using a 1/2-in. diameter, 2 in. long specimen. The specimen is soaked at 1000°F for 12
A STUDY OF THE EFFECT OF VARIOUS BINDERS AND ADDITIVES ON HOT STRENGTH OF MOLDING SAND

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Molding sand must possess an unusual combination of properties to successfully fulfill the requirements of the various steps in the molding and casting cycle. Initially the sand must be relatively weak and “flowable” so as to conform readily to the pattern during the molding operation. After molding the sand should have sufficient green strength to withstand handling. During pouring, surface hot strength must be developed rapidly to resist severe thermal shock and erosion by heavy turbulent liquids; somewhat later general strength must be developed by the entire mold to support the fluid pressure of the liquid metal and remain true to pattern dimensions. After the metal has solidified the sand must revert to a friable material which will allow easy removal of the castings. The used sand should then be amenable to remixing and use for another cycle.

Most molding sands actually develop the general sequence of characteristics described in a qualitative sense. However, successful casting requires that the sand have specific quantitative values of strength and ductility for specific types of castings. Inasmuch as little basic information is available relative to the effect of various sand components on sand characteristics it is necessary to develop specific mixtures by trial and error. This report presents such basic information

![Fig. 13.134 — Severe rattail condition.](image)

![Fig. 13.135 — Typical buckling type expansion scrap.](image)

![Fig. 13.136 — Sands represented by black circles are the type which produced iron castings with rattails.](image)

The confined expansion test is made on a 1 1/4-in. diameter, 2 in. long specimen with a 1/2-in. diameter hole through the center. The specimen is rammed in a fused quartz tube so that the radial expansion is restrained. The sand, therefore, is free to expand along the long axis only of the tube. The specimen is rammed with a 1/2-in. hole so that it will reach uniform temperature quickly.

As quartz softens at 2500 F the micrometer frame in the hot zone of the furnace must be supported from below to prevent sagging. It should be remembered that the graph was constructed on the basis of a fixed size and shape of gray iron casting. For other metals, other patterns, or any other conditions, the relationship between the physical properties and the scrap may be somewhat altered.

Sands represented by the black circles are sands that produced iron castings with rattails. Since the expansion of molding sands is not readily reduced, it becomes necessary to lower the hot strength, increase the hot deformation by additives such as cereal binders, cellulose materials, seaweed, and exercise control on mold hardness and moisture.

The illustrations in Fig. 13.137 and Fig. 13.138 show examples of retarding rattailing tendencies of gray iron molding sands.
Fig. 13.137 — Photo showing how cereal additions may control rattailing.

Fig. 13.138 — Photo showing how additions of wood flour and screea retard rattailing.
as data on the effect of various binders and additives
on hot strength of synthetic molding sands in the
range of 2500 to 2500°F. No attempt has been made to
evaluate the requirements for eliminating various
defects or producing successfully various types of
castings.

SCOPE OF PRESENT REPORT

The simplified synthetically bonded sand mixtures
used in this study of hot compressive strength consist
of blended sand, selected sand binders, and water. Clay may be considered as the primary binder
for mixtures of this type. Additional materials, fall
in the general categories of organic binders and addi-
tives, which may be introduced to control texture,
strength, and other characteristics. The organic bind-
ers may be considered secondary sand binders or mod-
ifiers of the primary clay binder. Additives serve as
fillers or in some other nonbinding capacity and are
not considered to add coherence.

The various commercial clay binders vary consider-
ably in the amount and nature of the principal clay
minerals present. For example, the principal mineral
in western bentonite is sodium montmorillonite; in
southern bentonites it is calcium montmorillonite;
and in fireclay it varies widely, but is principally
kaolin, with smaller amounts of other minerals such
as montmorillonite or illite. The strengths of the
various clays cover a wide range. In this investigation
the amount of clay binder for study was selected so
as to have practical foundry workability, a green
strength adequate for handling, and a hot strength
within the limits of the testing equipment.

It is well known that the strength of sand-clay-water
mixtures can be varied by changing the clay or water
content. In order to evaluate these effects quantita-
tively, western bentonite was tested in various con-
centrations and with various water contents. A refer-
ence mixture of western bentonite was also used to
evaluate the effects of a number of modifiers and addi-
tives. Foundry experience has shown that the com-
monly used clay binders are affected similarly by like
modifications. Thus, while any one of the various
clays could have been selected for the study, west-
ern bentonite was chosen because it represents the
best known and most commonly used foundry clay.
Water content in all mixtures was held as close as
possible to 5 per cent except in those mixtures of
western bentonite concerned with the study of water
as a variable.

The modifiers were tested as single binders in a one
per cent mixture with sand and water as well as in a
mixture containing sand, 2 per cent western bento-
nite, one per cent of the organic binder and 3 per
cent water. The effect of the modifier alone as well
as its effect with clay binders was shown.

In the case of the various additives studied, one per
cent was not enough to produce a definite effect on
the sand mixture. Iron oxide and wood flour were
therefore tested in a 5 per cent concentration and
silica flour in both 5 and 20 per cent concentrations.
Additives of this type are used in synthetically bonded
sands only when required by unusual molding condi-
tions.

PREVIOUS WORK ON THE PROBLEM

A literature survey was made of investigations on
refractory materials, ceramics, and molding sands at
elevated temperatures; a selected bibliography is ap-
pended in chronological order. Expansion and con-
traction on slow heating and on shock heating by
sudden immersion in a hot furnace have been studied
by various investigators. Bodin studied compressive
strength of refractories using small cube speci-
mens.

Dietert and his coworkers developed a furnace heated by
silicon carbide elements and investigated ranges of strength at various temperatures which correlate with the production of good castings
for various metals and alloys. A project concerned
with improving elevated temperature testing proce-
dures has been carried on at Cornell University by
the Sand Division of the American Foundrymen's Soc-
iety and reports of this work have been presented by
York, Flishar, Young, Williams, and Röder.

Expansion and compressive strengths of 4 per
cent western bentonite and 10 per cent fireclay mix-
tures have been studied extensively. Grover and his
coworkers have made important fundamental contribu-
tions to the knowledge of clay minerals and the
mechanism by which clays develop green and dry
strength in molding sands. Wheeler and Metcalf
studied practical applications of high temperature tests in the
steel foundry.

Salt studied high temperature tests in relation to
cast iron foundling. In spite of the large amount of
material written about refractories and molding sands,
there is little information on the effect of specific,
commonly used materials on the hot strength prop-
eries of sand-clay aggregates.

EQUIPMENT AND METHODS

Standard methods for sand testing as specified by
the American Foundrymen's Society were used wherever applicable methods were available. The sand
mixtures were made up as carefully weighed 3000
gram (dry weight) batches. The sand used was AFS
Secondary Standard Test Sand. Percentages of sand
and binder or other additives were based on the total
weight before adding water. All batches were placed
in an 18 in. laboratory muller and dry mixed 2 min.

Water was added in the mixer after which mixing
was continued for 5 min. Moisture content was deter-
mined after mixing by the loss in weight on drying at
221 to 230°F, and expressed as a percentage of the
moist sample weight. The mixed sand then was passed
through a 4 mesh foundry screen into half-gallon
mason jars which were immediately sealed with rub-
er stoppers, care being taken to avoid compacting
the sand in the jar.

The jars were inverted occasionally to prevent
concentration of moisture. Test specimens were pre-
bred by weighing out sufficient sand to make a
cylindrical specimen 1/2 in. in diameter by 2 in. long.
The sand was compacted by three blows of a 1/2-in.
diameter sand rammer in a specimen tube with a
high quality ground and polished inside surface. All
specimens were maintained within a tolerance of
±0.02 in.
Two different furnaces were used for making the compressive strength tests—one was heated by a carbonadium "glutide" and the other by a group of six "globars." The furnaces were connected by testing several duplicate specimens in both furnaces at several temperatures, and the results were in close agreement. The glutide furnace was much preferred, however, because it has an oxygen pit so that specimens may be seen and examined for cracks or other defects during heating, and also because it has an improved loading and weighing system. Weighing in the glutide furnace is accomplished by a Bourdon tube gage with a rider, and in the glutide furnace by a mercury manometer and check valve.

In most cases two to four hot compressive strength tests were made at each temperature. A total of 101 tests were made at 33 temperatures. At ten of the temperatures four tests were made, at twelve temperatures three tests were made, at twelve temperatures two tests were made and at one temperature only one test was made. The standard deviations from the average at each temperature shown both in psi and as a percentage of the average test value at that temperature.

The average standard deviation in per cent for all of the temperatures is 3.49 per cent. This statistic implies that the chance of a single test falling in the range of the average ± 3½ per cent is better than 2 to one. After the original tests were completed the graph was examined critically and 11 points were suspected of possible inaccuracy. These points were checked with a total of 47 additional tests.

Most of the checks points were so close to the original points that in nine of the 11 cases the original averages were used. In the other two cases the check test values were used because they were more nearly in agreement with the values for nearby temperatures, and it was assumed that some of the specimens in the first group of tests were defective.

The outlined procedures were followed throughout this investigation. Smooth curves were drawn through the plotted points wherever possible. In a few cases, however, the points were somewhat erratic over limited ranges, and the curves were therefore shown as dotted lines indicating some uncertainty in this range.

From the fact that the average deviation was found to be 3.49 per cent of the test value, deviations of a point from a smooth curve considerably greater than this amount should be given considerable consideration of validity depending on the general form of curve at the point.

The term "dry strength" and "maximum hot strength" have been adopted to simplify the discussion of data. "Dry strength" refers to the highest strength level developed in the range of 200 to 500°F by heating at those temperatures for 12 min. It should be noted that this definition does not correspond to that given in the Foundry Sand Testing Handbook as strength produced by drying at 221 to 250°F for 2 hr for practical purposes the two values are equal. "Maximum hot strength" refers to the highest strength developed in the range of 1500 to 2200°F which precedes extensive fusion.

**Properties of Simplified Western Bentonite Mixtures**

*General Strength-Temperature Relationship*

In order to establish a standard sand mixture with which other mixtures could be compared, a simple synthetically bonded sand was prepared containing 98 per cent AFS Secondary Standard Test Sand and 2 per cent western bentonite. Water was added to make 3.9 ± 0.1 per cent based on the moist weight. The hot compressive strength of this mixture is shown as the middle curve in Fig. 13.139.

A rapid increase in strength occurs between 200 and 400°F. It is in this range that free moisture is evaporated. It has been found that if the specimen is exposed for a long time at a temperature of 212°F it attains the same strength. In these tests the short exposure time of only 12 min required a considerably higher temperature for complete evaporation of free moisture. As the temperature is increased from 400 to 800°F the strength drops slightly. From 850 to 1750°F the strength again increases steadily and sharply.

As temperature is raised above 1750°F, the strength drops sharply from 1750 to 1900°F and then rapidly from 1900 to 2500°F where the tests were discontinued. At 2500°F the hot strength was reduced to 6.4 psi.

The mechanism by which clay binders develop gradually increasing strength in the range of 200 to 1800°F has not been ascertained. As a working hypothesis extension may be made of the classic investigations by Grim and Cutberv of the process by which "dry strength" is developed. The essential feature of this process depends upon the gradual elimi-
The interaction of the flakes and water are assumed develop strong bonding forces which resist volatilization of the water at temperatures considerably in excess of the normal boiling point. At temperatures greater than 800°F, the attractive forces are considered to be gradually overcome and successive layers of the water molecules are disrupted thus drawing the crystal plates closer together.

The bonding forces between flakes thereby become greater, resulting in a progressive increase of hot strength. The occurrence of physical-chemical reactions in this range should also be considered. No information, however, is available in this connection.

A gradual loss of weight over this temperature range has been noted for both southern and western bentonite sand mixtures. This may be interpreted as evidence for gradual volatilization of water in this range as postulated by the mechanism described.

**Effect of Water Content**

In order to study the effect of water, the standard reference mixture of 2 per cent western bentonite and secondary standard test sand was mixed with a low water content (1.60 per cent) and a high water content (5.58 per cent). In Fig. 13.139 these curves are compared with the standard mixture with 3.01 per cent water. The shape of the curve is approximately the same regardless of water content, except that the low water sample seems to be slightly more erratic.

Doubling the water content nearly doubles the hot strength in the range from 400 to 1900°F. From 1900 to 2500°F the effect of water is still apparent but not pronounced. This may be due to improved mobility of the clay crystals in the green state in the high water mixtures, resulting in more efficient positioning of the clay crystals. It is apparent that water content has a strong effect on hot strength and that it must be carefully controlled.

At the lower temperature end, the curves cross. This is because more water must be evaporated from the high moisture specimens and they are therefore slower in developing dry strength.

**Effect of Clay Content**

Figure 13.140 shows the effect of varying the clay content on the form of the strength-temperature curve. The central curve is that of the reference mixture containing 2 per cent western bentonite and 3.01 per cent water. Mixtures were prepared with half and twice this amount of bentonite, keeping the water content constant. These mixtures, contained one per cent bentonite with 3.12 per cent moisture, and 4 per cent bentonite with 5.10 per cent moisture.

In order to study the effect of high and low clay contents with proportional amounts of water two further mixtures were made, and the test results are shown as the top and bottom curves on Fig. 13.141. These mixtures contained one per cent clay, with 1.70 per cent water and 4 per cent clay with 5.96 per cent water. The general shape of all the curves is the same in that a level of dry strength is achieved at some temperature from 300 to 500°F and as temper-
ature is raised, the strength does not change appreciably for several hundred degrees.

Thereafter, at about 900 F an increase in strength begins which continues until the temperature of maximum strength is reached. For western bentonites the zone of maximum hot strength is relatively broad and extends from 1600 to 1900 F. At temperatures above 1900 F the strength drops sharply to less than 10 psi at 2500 F.

From the curves for 1, 2 and 4 per cent bentonite at approximately 3 per cent water content it may be seen that doubling the bentonite increases the strength about 50 per cent in the temperature range from 100 to 1900 F. If, however, the water is increased proportionately with bentonite (one per cent bentonite with 1.7 per cent water, 2 per cent bentonite with 3.04 per cent water and 4 per cent bentonite with 5.96 per cent water), the effect of increasing the bentonite is much larger; doubling the bentonite content then approximately doubles the strength in the 100 to 1900 F zone. It should be recognized that these relationships hold only for the limited range of water and clay contents specified.

The strength curve for one per cent bentonite with 1.70 per cent water seems to be somewhat erratic; several small maxima may be seen. It was thought that occurrence of the peaks might be due to experimental error but the variation amounts to 10 to 40 per cent of the test value, and the indication of similar maxima in the one per cent bentonite, 3.12 per cent H2O curve suggests that the maxima may actually occur. Indications of such multiple peaks in the other curves may also be seen in the range from 1600 to 1900 F.

**COMPARISON OF VARIOUS OTHER CLAY MIXTURES WITH WESTERN BENTONITE MIXTURES**

Since clays other than western bentonite are sometimes used as the primary binder in foundry sand, several other clays were studied for comparison with western bentonite. These included a commercial fire clay from Akron, Ohio (containing kaolin as its principal mineral), which is used by steel foundries particularly for heavy castings. White kaolin shows the effect of the mineral in as pure a form as it is readily available. A southern bentonite is used extensively for cast iron sands, and an Albany sand containing the clay with which it occurs in nature.

**Ohio Fireclay**

Figure 13.141 shows the strength-temperature relation of the Ohio fireclay in a 5 per cent mixture with sand as well as the western bentonite reference mixture. Water content was 3.02 per cent. Although two and a half times as much fireclay as western bentonite was used in order to make a workable mixture, the hot strength at most temperatures was well below that of bentonite.

Drying produces a strength of 25 psi at 400 F. Little change in strength occurs from 400 to 1400 F. From 1400 to 1800 F a gradual increase in strength takes place. From 1800 to 2000 F the strength increases rapidly to a maximum of 186 psi. From 2000 to 2500 F the fireclay exceeds the strength of the bentonite reference mixture.

The principal difference in these clays, aside from the general lower strength level of the fireclay mixture, is in the temperature at which the maximum hot strength occurs. The fireclay maximum occurs at about 250 F higher than that of bentonite.

**White Kaolin**

Figure 13.142 shows the hot strength range for a medicinal white kaolin, in a 5 per cent mixture with a water content of 2.91 per cent. This mixture reaches a dry strength of 13 psi at 100 F. The strength is somewhat erratic, without the usual plateau from 100 to 900 F then increases rapidly from 1800 to 2100 F reaching a maximum of 100 psi, after which it again decreases in the range from 2200 to 2500 F.

This clay develops its maximum hot strength at a higher temperature than any of the other clays which were studied, having its maximum 200 F higher than the fireclay and 150 F higher than the western bentonite. Its general strength, however, is relatively low.

**Southern Bentonite**

A commercial southern bentonite, principally calcium montmorillonite was studied in a 2 per cent mixture at 3.12 per cent water content. The results are shown in Fig. 13.143. It has roughly one-fourth to one-half of the hot strength of western bentonite. A dry strength of 10 psi is reached at 150 F which decreases to 30 psi at 1450 F. Strength increases rapidly from 1450 F to a maximum of 90 psi at 1600 F, and then decreases to 3.1 psi at 2500 F.

The strength-temperature relation of southern bentonite has the same general features as western ben-
tonite. It is characterized, however, by a relatively low hot strength and a maximum hot strength at 1600 F, which is 125 F below that of western bentonite. This curve disagrees considerably with the work published by Dunbeck, which indicated a maximum of 35 psi at 1000 F for a mixture containing 4 per cent southern bentonite.

**Albany Sand (Natural Clay Bond)**

Figure 13.144 shows the strength-temperature of a fine-grained Albany molding sand. This sand is not directly comparable to synthetically bonded sands because its grain size and distribution are not the same. Albany sand has a median grain size of approximately 100 microns, with 5 per cent smaller than one micron. Silt is abundant, some organic matter is present, and sorting is very poor. It was found that 6.87 per cent water was necessary to produce a workable mixture.

The dry strength plateau developed by the synthetic sands is not obtained; instead from 100 F to 1900 F there is a steady increase to the maximum hot strength of 360 psi, after which the strength drops rapidly to 10 psi at 2300 F. It is generally considered that Albany is a low fusion sand, hence the location of the hot strength maximum as high as 1900 F was surprising. Severe shrinkage takes place from 1900 to 2300 F and the sand fuses to a hard body which does not disintegrate on cooling. Gas evolution from 2500 F to 2300 F caused gross swelling of the sample which is called bloating.

**EFFECT OF VARIOUS ORGANIC MODIFIERS ON A REFERENCE MIXTURE OF WESTERN BENTONITE**

**Gelatinized Corn Flours**

Gelatinized corn flours, next to clay, are the most commonly used binders in the steel foundry. They are usually used as a secondary binder with clay as the primary binder. Two mixtures were studied, one having one per cent corn flour and 58 per cent sand at a moisture content of 3.04 per cent, and the other a combination with one per cent corn flour, 2 per cent western bentonite and 97 per cent sand at 3.04 per cent water content. In Fig. 13.145, the hot strengths of these mixtures are compared with the standard 2 per cent western bentonite mixture.

With corn flour alone as the binder, the strength increases rapidly to a maximum of 250 psi at 450 F. As the temperature is increased, the strength drops to 6.1 psi at 600 F. When 700 F is reached the strength increases to 14.3 psi. This behavior was repeated again with a minimum of 2.45 psi at 800 F and a maximum of 10.2 psi at 900 F, after which the strength became too low to be measured accurately. The minima and maxima shown are possibly associated with the combustion characteristics of this organic binder. At 1200 F to 1300 F the specimen becomes light in color indicating that the carbonaceous materials are completely removed. At this point the strength is less than one psi.

When the corn flour binder is combined with bentonite, the curve characteristics are similar to those of the western bentonite reference curve but with modifications occasioned by the presence of the corn flour. At 500 F a maximum of 170 psi is reached, which
drops to a minimum of 70 psi at 600 F. This corresponds with the first minimum for the series with corn flour as the only binder. At about 730 F a maximum of 82 psi is reached corresponding with the second maximum in the corn flour curve. A slight drop in strength occurs at approximately 800 F and from 800 to 1900 F the strength of the combined binders is less than that of bentonite alone.

From these curves it appears that gelatinized corn flour serves two functions: first, it provides “early hot strength” which may be developed by air or oven drying or by the heat of the poured metal, and second, it burns out just before the sand reaches the quartz inversion point, thus providing a small amount of space into which the sand grains can expand. This reduces the possibility of cracking the mold surfaces, as is noted in practice.

Dextrine

Foundry dextrine, also a corn product, which is over 90 per cent soluble in water, was studied in the same percentages as those used for the gelatinized corn flour, one per cent as a single binder with 3.02 per cent water, and one per cent in conjunction with 2 per cent western bentonite and 3.00 per cent water. The hot strength curves are compared with the 2 per cent western bentonite reference mixture in Fig. 13.146.

Dextrine produces high early dry strength (210 psi at a 250 F). It also has a temperature range (450 to 580 F) where strength drops suddenly and then recovers markedly. After reaching a second maximum of 118 psi at 580 F the strength drops quickly to 14.5 psi at 800 F. At higher temperatures dextrine behaves differently from corn flour in that it maintains an appreciable strength at high temperatures. There is a minimum of 7 psi at 1500 F, a maximum of 21.5 psi at 2000 and at 2500 F, the highest temperature tested, the strength is 12.5 psi.

When dextrine is combined with western bentonite it increases hot strength over most of the temperature range. The increase is especially evident at 375 F, 625 F and 2200 F. These maxima occur at slightly higher temperatures than those for the one per cent dextrine mixture without bentonite. From 2200 to 2500 F dextrine has a strong effect on the sand, producing a hot strength three to four times that produced by bentonite alone.

Dextrine, as shown by its effect on the reference western bentonite mixture, is useful for producing early hot strength which may help resist cutting and erosion. At high temperatures it adds slightly to the strength of the clay rather than decreasing it as do the gelatinized corn flours.

Lignin

Lignin is a by-product in the sulfite process of paper manufacture. Some of this material is used both in liquid and powder form as a molding and core sand binder. A typical powdered lignin binder was selected and tested in the same percentages as corn flour and dextrine with the results shown in Fig. 13.147. Like corn flour and dextrine it develops high dry strength. It begins to break down at 500 F and the strength from 500 to 2000 F drops steadily to
about 8 psi. From 2000°F to 2500°F there is a slight increase in strength. Like dextrine, lignin produces strength effects at temperatures far above the point where it is expected to burn out completely.

When lignin is combined with bentonite (one and 2 per cent, respectively) it increases hot strength considerably at temperatures up to 800°F. Above this point the lignin causes the mixture to be weaker than it would be with bentonite alone. The high temperature maximum at 1620°F is narrow and sharp, lower than that of bentonite alone and shifted toward lower temperatures. At 1850°F 2 per cent bentonite produces 360 psi, while 2 per cent bentonite plus one per cent lignin produces only 60 psi.

From this it appears that lignin may be useful in reducing hot strength above 800°F, if this is necessary, and at the same time provide dry strength and possibly some quick hot strength to resist erosion by flowing metal.

Lignin binders are hygroscopic hence care should be exercised when they are used to see that the molds are used soon after being made or are adequately dried in order to avoid excessive water content.

**Pitch**

Pitch is not widely used in molding sands but finds considerable use in cores, particularly wherever a core is made with a sand containing clay where an oil core binder cannot be used economically. A finely ground commercial grade as supplied for foundry use was selected and mixtures were made containing one per cent pitch and a combination of one per cent pitch with 2 per cent western bentonite. Water contents were 3.08 and 2.92 per cent, respectively. The hot strength curves are shown in Fig. 13.138.

The hot strength of the one per cent pitch mixture is unlike any binder previously tested. In general its strength is low. A maximum of about 4 psi occurs at 350°F due to evaporation of the moisture and another, 18 psi at 950°F. From 1000 to 1100°F the strength drops rapidly and above this point no measurable strengths were found.

The hot strength of sand containing 2 per cent western bentonite is only slightly changed by the addition of pitch. The two maxima developed by pitch alone are reflected in the curve for the combined binders by slightly higher strengths over a limited range of temperatures. Pitch has its most pronounced effect above 2000°F where it adds considerably to hot strength. At 2500°F, for instance, the strength is increased from 12.3 to 38.5 psi by the addition of one per cent of pitch.

The failure of pitch to produce any pronounced change in the hot strength of a sand-clay-water mixture, except at high temperatures, does not condemn it as a binder. It serves a useful purpose in high strength cores containing clay which are first baked and then cooled to room temperature. Under these conditions the pitch melts during baking and solidifies during cooling, giving the core dry or baked strength so that it may be handled and placed in the mold.
EFFECT OF VARIOUS ADDITIVES ON A WESTERN BENTONITE REFERENCE MIXTURE

Wood Flour

Wood flour, which has previously been reported as having a beneficial effect in preventing veining defects in phosphor bronze castings, was tested at 5 per cent content with 2 per cent western bentonite and 3.06 per cent water. Wood flour as a single additive was not tested. Figure 13.149 shows the strength-temperature curve for the wood flour-bentonite combination with that of the 2 per cent bentonite reference mixture.

Examination of the curve shows that wood flour has the most drastic effect of any material studied in reducing hot strength. At 500 F the dry strength maximum is reduced from 78 psi for bentonite to 8.5 psi for the bentonite-wood flour combination. Strength then drops to 4 psi from 700 to 900 F. A maximum of 73 psi is reached at 1610 F. From 1610 to 1900 F, although the curve is nearly straight, the type of failure changes completely.

From 1610 to 1725 F the specimens break suddenly and with a shear failure along a diagonal plane about 45 to the axis. As 1725 F slight bulging of the sides is noticed with a shear failure, and above this temperature the failure is plastic, the cylinder deforming into a barrel shape. All other mixtures investigated break with a shear failure up to 2200 F. With increased temperatures the strength drops rapidly to 2.5 psi at 2500 F. Wood flour appears to be the best agent tested thus far, for reducing the hot strength produced by bentonite at all temperatures studied.

Iron Oxide

A commercial grade of ground iron oxide prepared especially for foundry use was tested in a sand mixture at 5 per cent with 3.02 per cent water and in another 5 per cent mixture with 2 per cent western bentonite and 2.94 per cent water. In Fig. 13.150 the strengths of these two mixtures are compared with the standard 2 per cent western bentonite mixture.

Iron oxide alone produces little or no strength at room temperature and is not usually considered a sand binder. It is sold and used principally as a remedy for veining defects in steel castings, but foundry authorities do not agree as to its accomplishment of this result. At temperatures of 300 F and over, 5 per cent iron oxide produces strengths averaging about 10 psi. Above 1700 F the strength decreases gradually to 4 psi at 2500 F.

When combined with western bentonite, iron oxide raises the strength of the sand at nearly all temperatures and raises the temperature at which maximum strength occurs by nearly 100 F. At temperatures above 2000 F the iron oxide causes a large increase in strength, which from 2300 to 2500 F amounts to 700 per cent. The curve indicates that iron oxide is useful for increasing hot strength at all temperatures. It also raises the temperature at which the hot strength maximum occurs.
Silica Flour

Silica flour is a common addition to molding sand, particularly for steel castings where it is used as a filler to decrease the amount of void spaces in the sand and thus reduce the penetration of metal into the mold. Silica flour is used in wide range of concentrations; mixtures occasionally contain as much as 50 per cent.

In studying the effect of silica flour, a mixture was made with 5 per cent silica flour and no bentonite and another with 5 per cent silica flour and 2 per cent western bentonite. Water contents were 3.04 and 2.98 per cent respectively. A third mixture contained 2 per cent western bentonite with 20 per cent silica flour and a water content of 3.06 per cent. Figure 13.151 shows the hot compressive strength of these mixtures along with that of the 2 per cent western bentonite mixture for comparison.

The strength of the 5 per cent silica flour mixture varies from 6 to 14 psi with a maximum of 2100 F. The production of hot strength by an inert material cannot be explained except as the result of mechanical action.

When 5 per cent silica flour is combined with 2 per cent western bentonite, the strength is raised over the entire temperature range studied, the largest increase being in the zone about 1700 F. When the silica flour is increased to 20 per cent with 2 per cent bentonite, much higher strengths are produced. The dry strength reaches 150 psi at 400 F and increases to 740 psi at 1750 F. At 2100 F a small rise in strength produces another maximum of 334 psi. At 2500 F the strength drops to 70.5 psi which is, however, high for this temperature.

Silica flour is an excellent material for increasing the hot compressive strength of sand mixtures over a wide temperature range. It can be added in amounts from small to large percentages to produce almost any practical hot strength required by the molding conditions.

Summary

It may be concluded from these data that clay establishes the general shape of the strength-temperature relation of molding sands. By selecting a strong clay, strong sands may be produced with a minimum of clay. Western bentonite produces the greatest hot strength in a given concentration. If lower hot compressive strength is needed without sacrificing green strength, it may be produced by the use of southern instead of western bentonite. The temperature at which maximum hot strength occurs varies from 1600 F for southern bentonite, to 2200 F for pure kaolin.

Increase in water content of a molding sand increases its hot strength, particularly in the range from 400 to 1900 F.

Increasing clay content also increases hot compressive strength. In order for an increase in clay content to contribute most effectively to strength, the water content should be increased proportionately. Change of clay content is the simplest method of increasing or decreasing hot strength if a change is needed over the entire temperature range.

Organic binders are useful for modifying hot strength over limited ranges of temperature. These agents generally raise the strength in the zone from 400 to 800 F and thereby provide resistance to erosion and cutting by the flowing metal. Gelatinized corn flour lowers strength slightly from 800 to 2000 F. Dextrine increases strength above 2000 F. Pitch has little effect except at temperatures over 2000 F where it increases strength. Lignin increases hot strength from 400 to 800 F but at higher temperatures reduces strength by large amounts.

Of the various additives studied, wood flour most drastically reduces strength at all temperatures. Wood flour also increases ductility in the range of 1900 to 2100 F.

At 1900 F, a cylindrical specimen, when compressed, deforms into a barrel shape without cracking; without wood flour the specimen breaks at this temperature with little deformation. The plasticity introduced by wood flour minimizes the cracks which under certain metal conditions produce "vein" defects.

Iron oxide and silica flour increase hot strength at nearly all temperatures. The increase is most pronounced at temperatures over 2000 F.

A summary of the range of strengths which can be produced using 2 per cent western bentonite and 3 per cent moisture content molding sand is presented in Fig. 13.152 by curves of maximum and minimum strengths produced in this mixture by the addition of various binders and additives. This area may be made still broader by altering water or clay content.
BIBLIOGRAPHY

This chronological list contains both references cited in the text and additional reading matter on the subject covered in this report.


RETAIRED PROPERTIES

Retained strength may be defined as the strength (generally measured in the laboratory as compression) remaining after a molding sand has been subjected to shock heating, as when a mold is poured and permitted to cool until shakeout or subsequent processing. The volume affected is the distance from the mold-metal interface to the original unaltered green or dry sand molding material. The degree of heat penetration results in a "layer effect" and is dependent upon the quantity of available heat, time and oxidation.

For example, the interface layer in a larger mold will have the original clay bond or organic additives largely destroyed. The degree of alteration diminishes with distance from the metal interface. In order to control the degree of retained strength, a knowledge of how all the component bonding and facing additives behave over all temperature ranges is mandatory. It is also important to know whether these materials are thermosetting or thermoplastic, and the manner in which they are affected by oxidation.

Factually, control of retained strength is occasioned by the adverse effect of difficult shakeout or knockout, and the breakdown of massive lumps or agglomerates for reprocessing. Retained strength is affected by sand grain fineness, density, composition, heat flow time, and many other factors, such as:

Types of bond as it contributes to strength,
Types of facing or additives.
Moisture content.
Pouring temperature of the metal.
Standing time of the molds after pouring.
Venting.

In several papers by Sanders* it has been stated that dry strength and retained strength are not the same.

although they are often related. Retained strength is that dry strength of a molding sand which causes sand to roll over the end of shakeouts as lumps, even though the sand may be cooled below dry strength temperatures.

In general, the more fines which occur in a sand mixture, the more retained strength the sand may possess. This is believed due to the fact that the more fines (or inert fines) which a sand may possess the more temper water is required. Excess water in many sand mixtures generally creates higher retained strengths. In some cases this is desired, in others it is not.

Naturally bonded sand mixtures which possess high clay and high water generally have high retained strengths. Additions of bond are generally conducive to higher retained properties. Western bentonite and fireclay appear to have more retained sensitivity than southern bentonite mixtures; generally, the lighter the bond, the lesser the temper water required. It is the reaction of bonding action between the two that prevails.

Coral flour, wheat or rye cereals generally add retained properties to molding sand mixtures. Seacoal additions generally increase retained properties as the temper water is increased. The finer coals generally require more water; therefore, higher retained properties result. Pitch in molding sands generally increases retained properties. Pitch, in order to be effective, requires higher water content which in turn increases retained strengths.

Most of the organics, such as molasses water, glutrin water, dextrose water and others, generally increase the retained properties if they are not burned completely from the molding sand mixture. It has been found that the best way to avoid retained strength, if that is desired, is to use cellulose products such as wood flour. If the water is not in-

* Sanders, C. A., American Colloid Co., Skokie, III.