THERMAL STABILITY OF BENTONITES IN FOUNDRY MOLDING SAND*

by

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ABSTRACT

THE EFFECTS of heat on the behavior of sodium and calcium bentonite in bonding foundry sands were studied.

Tests such as differential thermal analysis, viscosity, and melting or vitrification temperatures do not indicate the suitability of a bentonite for foundry use.

The deterioration temperatures of sodium and calcium bentonite are 1180° and 600°F respectively.

Reactivities of bentonites with cereal as affected by temperature and mulling were also studied. Flowability of sands, defined as mold densification in this paper, is better with heated calcium than sodium bentonite.

Heating bentonites alone does not simulate the conditions encountered in heating bentonite-sand mixtures in a mold.

INTRODUCTION

SYNTHETIC molding sands, used by the foundry industry to contain and shape liquid metal, are essentially composed of a pure quartz sand, bentonite, and an additive, such as pulverized coal or cereal, and water.

The molding sand is mixed in a sand muller and is used to prepare a mold. Molten metal is poured into the cavity. After the metal solidifies, the resulting casting is removed from the mold for final cleaning.

Most iron foundries re-use the sand indefinitely, but steel foundries favor the use of facing sand, prepared from all new materials, for the surface against the casting, with the bulk of the mold made with the re-used sand.

The foundry literature (Zrimsek and Vingas, 1960, 1961a, b and c; 1962; Vingas and Zrimsek, 1961; Heine *et al.*, 1959; Ojala, 1962) contains considerable information on the properties of bentonite-bonded new sand mixtures. Few data have been presented on the rate and nature of changes produced by re-use.

The high temperature of the metal during casting heat-treats the molding

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sand to temperatures ranging from room to pouring temperature of the metal. At some temperature, the bonding agents in the sands become inactive, and are replenished by new materials. Knowledge of the effects of temperature on foundry molding materials is, therefore, important, to determine the amount of new materials to be added, and to know the rate of accumulation of inactive materials within the sand system as it recirculates. Such materials can promote many defects in the final casting (Ojala, 1962).

The experiments reported were concerned mainly with the behavior of bentonites heat-treated at various temperatures. The studies of heat transfer through molding sand conducted by Paschkis, 1945; Pellini, 1951; Ruddle, 1957; Marek, 1963, will be useful in applying these findings. Previously published data (Zrimsek and Vingas, 1960, 1961a, b and c, Vingas and Zrimsek 1961, 1962; Heine, *et al.*, 1959; Ojala, 1962) on new sand mixtures provide an understanding of the design of this experiment. The effects of heat-treatment systems that include combinations of variables encountered in regular foundry practice were investigated.

Some specifications for bentonites for foundry use call for tests for viscosity, liquid limit, gel strength, water repellency, fusion or vitrification temperature, differential thermal analysis, or ion exchange ability, which may relate to the mineralogy of the bentonites, but do not predict directly their suitability for making a satisfactory mold and a satisfactory casting.

Clays in general and bentonites in particular are added to foundry molding sands primarily to bind the aggregate together when making a mold. The mold must maintain its shape while the metal is poured and until the casting solidifies. The adhesive and cohesive forces of the sand-bentonite-water mixtures are evaluated by the resistance of the mixture to compression or shear in the green (undried) or dry state. Vingas and Zrimsek (1963) showed that the mechanical properties alone cannot predict the performance of adequately bonded aggregate for the production of defect-free castings.

The effects of heat-treated bentonites, when mixed with sand, on the mechanical and physical properties and on bonding ability and viscosity have been systematically evaluated. The temperature at which bentonites cease to act as bonds was determined. The limitations of the mechanical and physical properties to predict and evaluate the quality of re-used sands was shown. Foundry molding sands are complex aggregates, and heat treating the bentonites separately does not simulate the heat treatment induced by the casting process or their reactivity to additives such as cereal.

The tests used are described in the Foundry Sand Handbook, 7th edition, 1963.

EXPERIMENTAL

Two bentonites were investigated: a sodium (western) and a calcium (southern) bentonite, mined and processed in Greybull, Wyoming and Kosciusko, Mississippi respectively. The bentonite was dried to 7 per cent water content and ground so that 90 per cent was finer than a no. 200 sieve.

The behavior of the two bentonites after heat treatment was evaluated, with the water content of the sand mixture, the mulling response and ramming as variables. Tests were performed to evaluate the effects of cereal flour on heat-treated western bentonite and the effects of heat-inactivated western bentonite on new western bentonite.

Heat Treatment of Bentonites

The bentonites were heat-treated in a 10 × 9 × 13-in. electrically heated furnace. After the temperature was stabilized at the desired temperature, the bentonite contained in a 5½-in. i.d. by 10-in. high clay-graphite crucible was placed in the furnace.

A chromel-alumel thermocouple connected to a potentiometer was immersed in the bentonite sample. The sample was left in the furnace for at least 3 hr after the immersed thermocouple reached the stabilized temperature of the furnace.

Each of the bentonites was evaluated as received and after heat treatment to the various temperatures shown in the illustrations. The evaluation was performed on sand mixtures prepared by two methods of mixing, an efficient method and another that involved only stirring the aggregate.

The sand was a 51.3 AFS FN (Foundry Sand Handbook, 1963) Wisconsin pure silica sand, the sieve analysis of which is shown in Table 1.

TABLE 1.—SCREEN ANALYSIS OF BASE SAND USED

U.S. standard sieve no.	Retained %
20	0.0
30	2.6
40	19.3
50	30.1
70	24.4
100	15.1
140	5.6
200	2.4
Pan	0.6

Mulling

In the first method of mulling, 1250-g sand and 100-g bentonite to be tested were placed in a 12-in. Cincinnati muller and mulled dry for 15 to 20 sec. Water was added, and the mulling continued for 6 min more.

For the second method, 1250-g sand was placed in the muller, the wheels of which were removed, water was added, stirred with the plows only until distributed (30–35 sec) and the 100 g of bentonite was then added and stirring continued for an additional four minutes.

Each sand–bentonite–temperature–mulling combination was tested at five levels of water content, ranging from 2–5 per cent for the sand mixtures mulled with the wheels, and 3–6 per cent for those stirred.

Tests

The sand mixtures were discharged into polyethylene bags and tested for moisture content, green compression strength, green shear strength, dry compression strength, and dry shear strength at 3 rams. The density of the sand mixture was also checked at 1, 3, 5, 7 and 10 rams (Zrimsek and Vingas, 1961b). The sand mixtures were also riddled through a $\frac{1}{4}$-in. screen into a 250-cc volume and the density was calculated and reported as riddled density in lb. per ft^3.

Cereal Effects

The western bentonite, heat-treated to 1120°F., continued to act as a bond in sand. To study the reactivity of this heat-treated bentonite to cereal and compare it to the reactivity already established (Vingas and Zrimsek, 1963) in new sand mixtures, some limited data were collected.

A mixture of 1250-g sand, 62.5-g (4.75 per cent) heat-treated and as-received bentonite, and 12.5-g (1 per cent) cereal were mulled (with muller wheels on) as described above, at five moisture levels. The mechanical properties of these systems were used for comparison and determination of the effects of heat treatment on the reactivity of western bentonites to cereal.

Effects of Heat-Inactivated Bentonite

The western bentonite heated to 1180°F or above ceased to react as a bond when mixed with sand. Five per cent of the heat-inactivated bentonite at 1700°F was mixed with sand and new western bentonite (7.45 per cent), mulled as described earlier (with muller wheels on) at five water levels, and the physical properties checked. Subsequently, mulled sand containing 5 per cent new western bentonite and water was heated at 1700°F for three hours. This sand was mulled (with wheels on) with 7.45 per cent new bentonite at five water levels and the physical properties were checked. The physical properties of the two systems containing the heat-inactivated bentonite were compared to the system containing only new western bentonite (at the same level, 7.45 per cent).

Viscosity Tests

Sodium (western) bentonite when mixed with water exhibits viscosity, and it is common for some foundries to evaluate this property. The sodium bentonite as received and all heat-treated samples were also checked for viscosity. This was done by mixing 24-g (6 per cent) bentonite with 376 cm^3 distilled water in a Hamilton Beach model 3D mixer for 6 min. The suspension was then checked for viscosity with a Fann V.G. Viscosimeter at 600 rpm, and calculated in centipoises.

RESULTS

Because of the volume of data collected, all results are presented in graphic form. Not all the data on cereal are presented since doing so would be repetitive.

DISCUSSION

We studied the deterioration of bentonites and the behavior of molding sands containing heat-treated and deteriorated bentonites mixed with new, unused materials.

Several investigations (Hofmann, 1958; Grim and Cuthbert, 1945) have been conducted to establish the deterioration temperature of various bentonites. In Europe, where sodium bentonites are scarce, the investigators usually attempt to alter the calcium bentonite to sodium by treatment with sodium salts. In most investigations, the major variables encountered in regular foundry practice, such as water content, mulling response and ramming energy, are maintained constant. As shown previously (Zrimsek and Vingas, 1960, 1961a, b, Vingas and Zrimsek, 1961, 1962; Heine, *et al.*, 1959) molding-sand data, unless collected on a system basis, are almost impossible to analyze accurately.

This study shows the differences between sodium and calcium bentonites when heated and mixed thoroughly with sand and water.

Figs. 1 and 2 show the data on sands bonded with the western and southern bentonites before and after heat treatment, with the efficient mulling method employed.

The curves obtained with the 7.45 per cent bentonite-sand-water mixture before heat treatment are typical curves obtained with foundry molding sands (Zrimsek and Vingas, 1960, 1961a, 1961b, Vingas and Zrimsek, 1961, 1962; Heine, *et al.*, 1959).

Figs. 1 and 2 show that, as the heat-treating temperatures increase, the peak green compression strength (Figures 1(a) and 2(a)), green shear strength (Figures 1(b) and 2(b)), and the minimum density point (Figures 1(f) and 2-f)) shift to higher water levels.

When peak green compression strength (Fig. 3) is plotted versus temperature, the strength of the western bentonite bonded sand drops beyond 1150°F and that of the southern, beyond 600°F. The drop in strength beyond these temperatures is drastic for the western and more gradual for the southern.

Similar indications are reached if the other strength values are plotted as a function of temperature and at other relatively equal water levels.

Figs. 4 and 5 show representative properties obtained at relatively low

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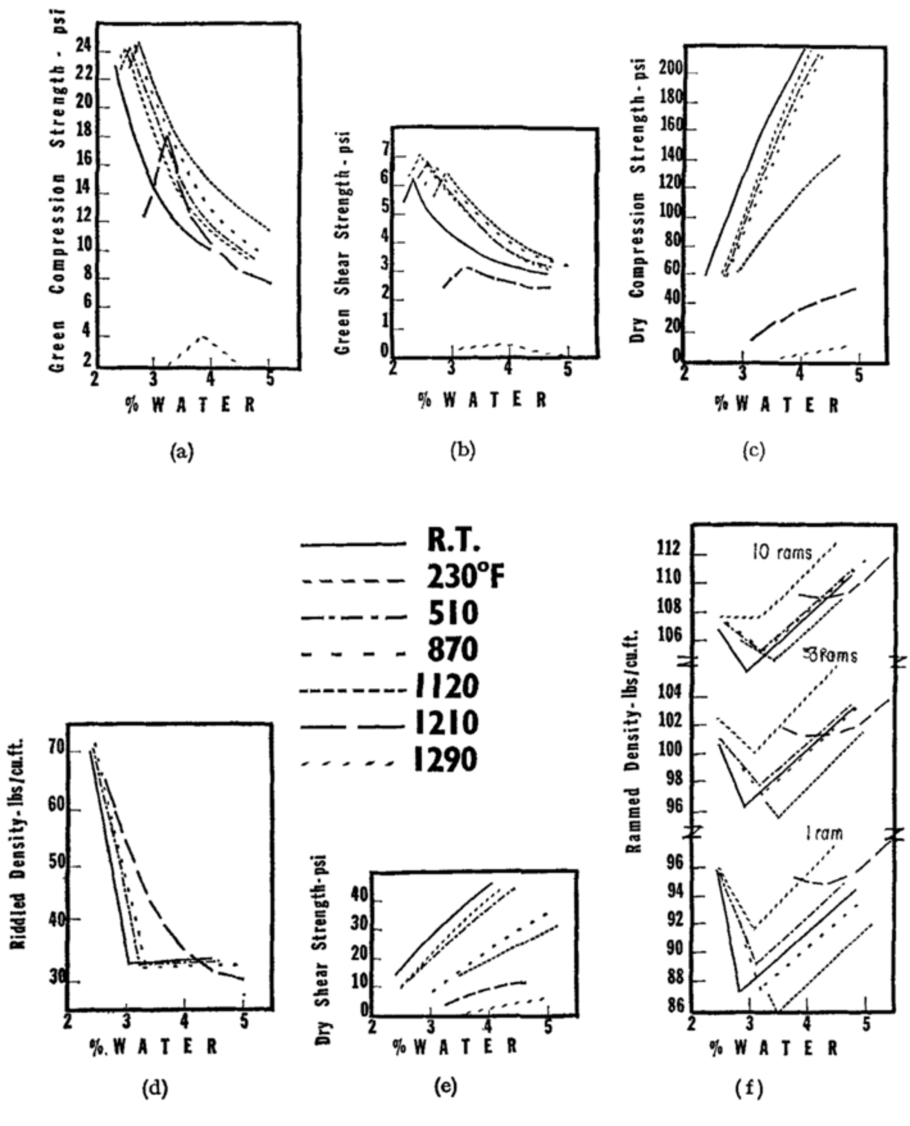

FIG. 1. Water content effects on green compression strengths (a), green shear strength (b), dry compression strength (c), riddled density (d), dry shear strength (e), and rammed density (f) of 7.45% western (sodium) bentonite bonded sands; western bentonites checked at room temperature and at the heat-treated temperature indicated; all properties shown at 3 rams except rammed density, which was also checked at 1 and 10 rams. Sands mulled for 6 min after water was added with wheels of muller on.

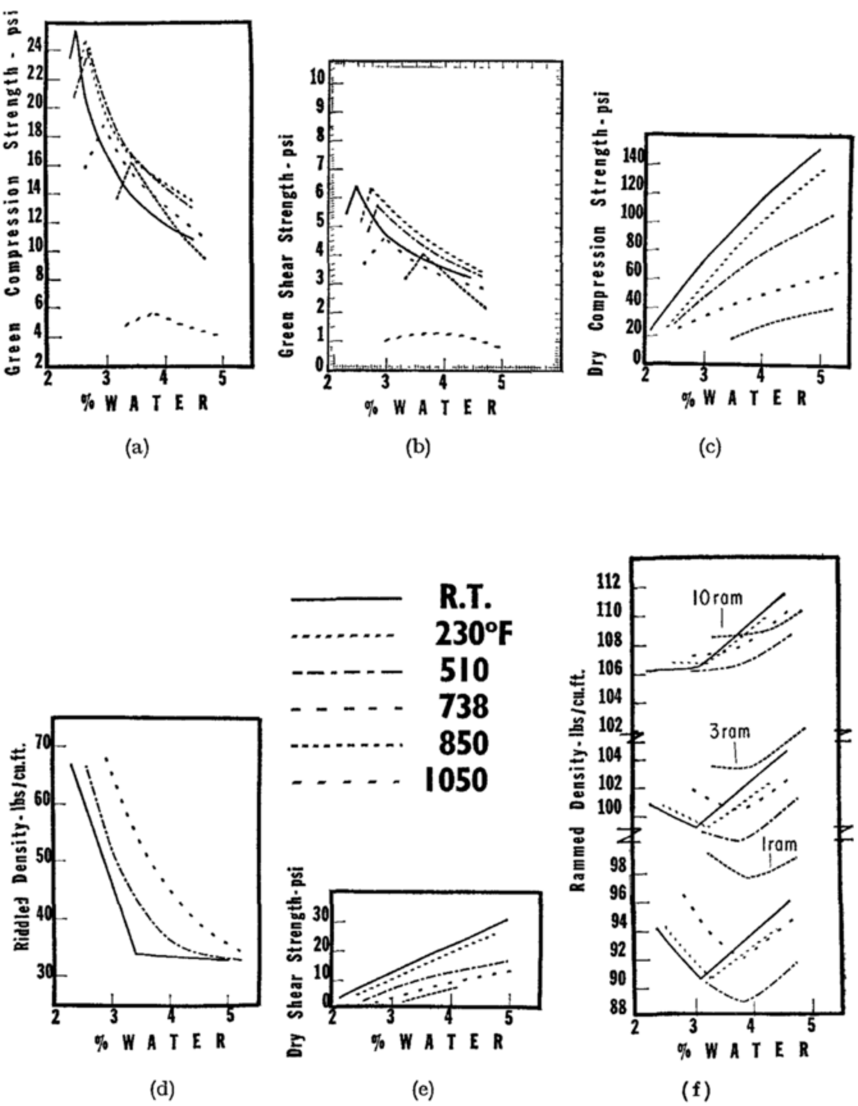

FIG. 2. Water content effects on green compression strength (a), green shear strength (b), dry compression strength (c), riddled density (d), dry shear strength (e), and rammed density (f) of 7.45% southern (calcium) bentonite bonded sands; southern bentonites checked at room temperature and at the heat-treated temperature indicated; all properties shown at 3 rams except rammed density, which was also checked at 1 and 10 rams. Sands mulled for 6 min after water was added with wheels of muller on.

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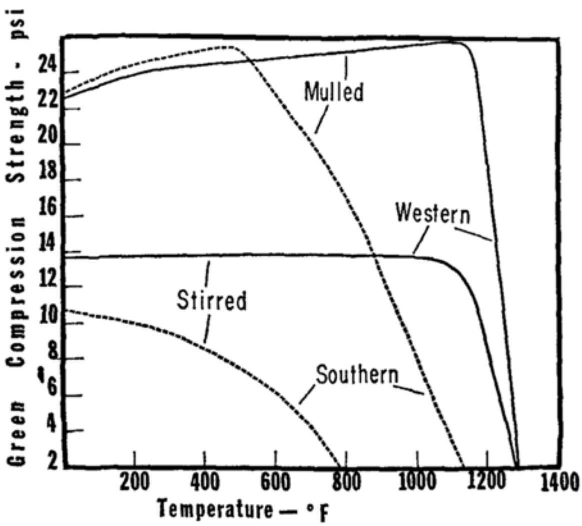

FIG. 3. Peak green compression strength as a function of the temperature at which the bentonites were heat-treated; mulled and stirred sands as indicated.

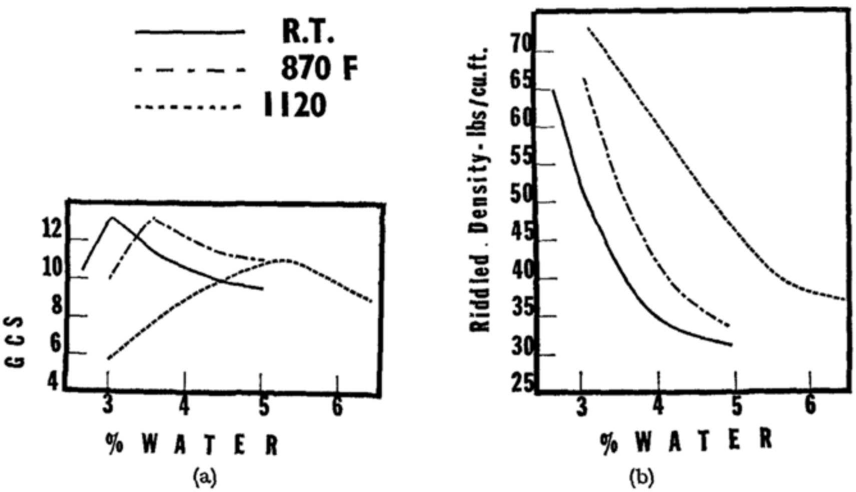

FIG. 4. Water content effects on green compression strength (a), and riddled density (b), of 7.45% western (sodium) bentonite bonded sands.

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mulling efficiency. The peaks exhibited by the green strengths, compression and shear, are reduced and the influence of water content is diminished. The resulting curved maxima occur at substantially higher water levels. At this low mulling efficiency level, if any of the green strengths are plotted at the same relative wetness versus temperature, the apparent deterioration temperature of southern begins at a lower temperature than when the sand mixture was thoroughly mulled. The ability of the bentonite after heat treatment to rehydrate, plasticize, and act as a bond is readily measured by the mulling response.

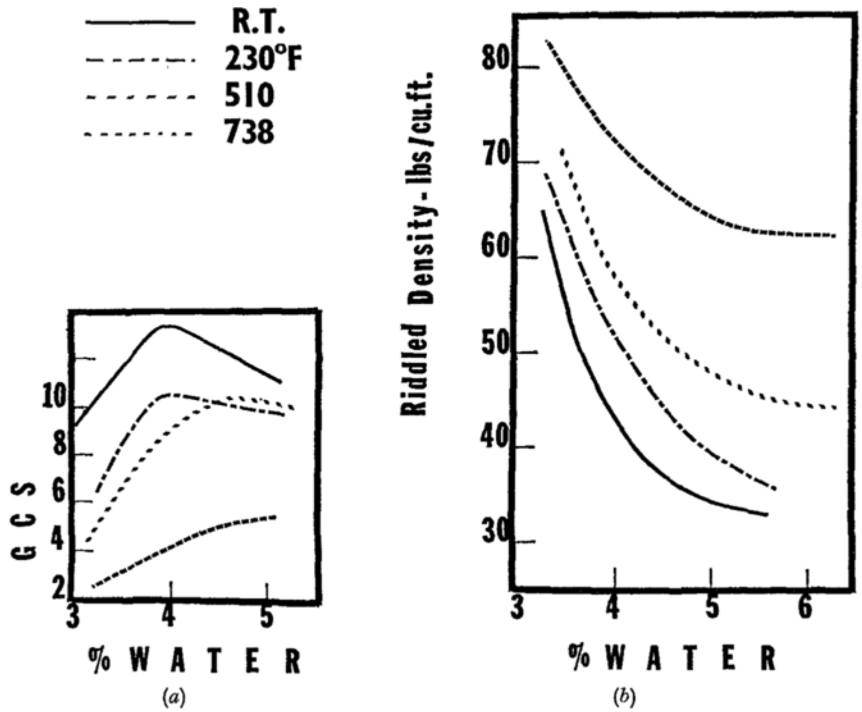

FIG. 5. Water content effects on green compression strength (a), and riddled density (b), of 7.45% southern (calcium) bentonite bonded sands.

The green strengths of the stirred western bentonite systems, although substantially reduced, still break at the same temperature, 1150°F, as did those efficiently mulled.

Density minima are also moved to higher water levels, and the replacement of the sharp minima by curves occurs at lower temperatures than with the high efficiency mulling.

The data on mulling indicate that temperature influences the rehydration of southern considerably more than western bentonite, as measured by

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mulling response. The same data, however, show that with the low mulling efficiency new as-received western bentonite responds to mulling more readily than southern. This is contrary to what was previously reported (Vingas and Zrimsek, 1961) when the low mulling efficiency was designed differently. In that work, the low mulling efficiency was simulated by placing the sand and bentonite in an 18-in. muller and mixing for 30 sec. Water was added, and the mulling was continued for 2 min more.

The direct relationship between 1- and 10-ram density differential (Zrimsek and Vingas, 1961b, 1963; Vingas and Zrimsek, 1962) and the percentage of bentonite present in a sand mixture, when checked at any water content beyond the minimum density point, is substantiated by this experiment.

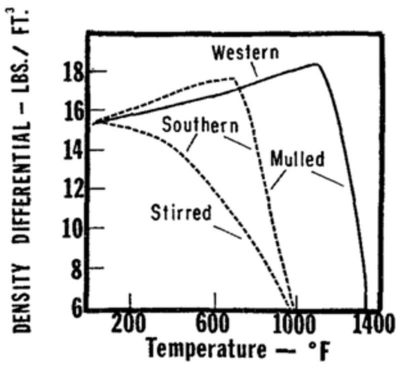

FIG. 6. Density differential as a function of the temperature at which the bentonites were heat-treated; mulled and stirred sands as indicated.

Fig. 6 shows the density differential plotted against temperature, and it substantiates the conclusions reached when strengths were considered in judging the deterioration temperature. The differential also shows that bentonite content increased with heat treating temperature because both the free and combined water in the bentonite were removed by heating, a variable not considered in the design of this experiment. The differential also shows the response to mulling, substantiating what was shown by the strength.

RIDDLED SAND DENSITY

It was shown previously (Zrimsek and Vingas, 1964), when molding sands were investigated for their ability to reproduce a particular casting dimension from that of the pattern, that the riddled density of the sand is the most significant property. In addition, they showed that the main disadvantage of bentonites in molding sands is the very narrow range of water after which a major change in riddled density occurs. Modern high-production molding machines do not consider this variable in their design. Riddled density is here

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considered synonymous to flowability, a term used by the foundry industry to describe response of mold densification.

Figs. 1(d), 2(d), 4(b), and 5(b) show the effects of water content on the riddled density of sands. They show that the density drops drastically over a very narrow water range as water is increased. As the heat-treat temperature increases, the drop becomes more gradual, particularly with southern bentonite.

TABLE 2.—WATER RANGE REQUIRED TO REDUCE RIDDLED DENSITY FROM 65 LB/FT^3 TO 40 LB/FT^3

Bentonite	Temp. °F	Water % From	Water % To	Water range
Western Mulled	Room	2.45	2.90	0.50
	510	2.55	3.05	0.50
	870	2 50	3.15	0.60
	1120	2.60	3.65	1.05
Southern Mulled	Room	1.35	3.20	0.85
	510	2.55	3.65	1.10
	738	3.00	4.40	1.40
Western Stirred	Room	2.70	3.60	0.90
	870	3.15	4.15	1.00
	1120	3.70	5.60	1.90
Southern Stirred	Room	3.20	4.20	1.00
	230	3.40	4.90	1.50
	510	3.60	Never reached	
	738	4.90	Never reached	

Table 2 shows the range of water required to reduce the riddled density from 65 lb/ft^3 to 40 lb/ft^3. At all conditions, the southern bentonite shows a larger water range than the western. This substantiates the statement made by foundrymen that southern bentonites are more flowable than western.

Heat treatment of the southern bentonite not only reduced the sensitivity of moisture to riddled density, but simultaneously increased the density achieved at minimum. For example, the minimum riddled density of the 738°F heat-treated, southern bentonite-bonded sand (Figure 5(b)) reached is 63 lb per ft^3 versus 33 lb per ft^3 for the new, as-received bentonite.

It should be remembered that many additives put in molding sands affect the flowability of bentonites. For example, Vingas and Zrimsek (1963) showed that cereal, when mixed with western bentonite, eliminates the narrow water range at which these sands are workable.

Effects of Cereal

The western bentonite heated to 1120°F was used to prepare sand mixtures with cereal flour in order to investigate the reactivity of cereal to the heat-treated western bentonite.

Fig. 7 shows the influence of 1 per cent of cereal on green compression strength for the 4.75 per cent bentonite system. Green strengths at low water content were reduced, and the comprehensive tests showed that the minimum density and comparable dry compression and dry shear strengths were realized at about 0.5 per cent higher water contents.

The systems at lower heat-treating temperatures showed no major effects on the reaction of cereal to the bentonites, and they are not included in this report. The shifts in water requirement closely followed the systems containing no cereal.

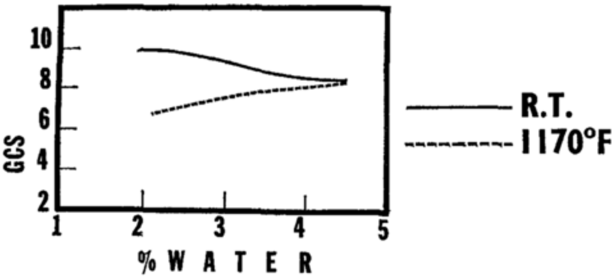

FIG. 7. Water content effects on green compression strength of 4.75% western (sodium) bentonite and 1% cereal flour bonded sands.

Effects of Heat-Inactivated Bentonite

As described in the experimental section, the western bentonite heat-treated to 1700°F, thus completely heat-inactivated, was used to prepare several mixtures. Five per cent of this heat-inactivated bentonite and 7.45 per cent new bentonite were mulled (wheels on) at five water levels. These mixtures were used for comparison with sand mixtures in which western bentonite was inactivated by heating a mixture of 5 per cent western bentonite and 95 per cent sand to 1700°F. The resulting sand, containing 5 per cent heat-inactivated bentonite and 7.45 per cent new bentonite, was also mulled (wheels on) at five water levels.

The mixture with bentonite heat-inactivated on the sand grains and subsequently bonded with new bentonite is not very different from the new sand mixed with only new bentonite. On the other hand, the sand mixed with the separately heat-inactivated bentonite increased the water requirement for peak green compression strength and minimum density by 0.7 per cent. This indicates that heat treating the bentonites separately and then adding them to sands does not exactly simulate what happens in practice (Zrimsek and Vingas, 1963).

Molding sands are complex aggregates. To be properly and comprehensibly investigated, each of the components must be varied independently and in conjunction with each other. Furthermore, heating the bentonite separately from the sand is not the perfect method for investigating re-used sands. The data presented should, therefore, be used with discretion.

It should be stated, however, that 1180°F and 600°F, which were established as the points at which western and southern bentonite respectively deteriorate as bonds, are below the vitrification temperature that has been reported (Grim and Cuthbert, 1945) to be the deterioration point.

Viscosity

Table 3 gives the viscosity in centipoises of the heat-treated western bentonite. It shows that viscosity quickly drops to 4.0 at 810°F from 20.0 at room temperature, although the strengths exhibited in the sand mixtures are unaffected. Judging utility of the bentonite as a bond by viscosity is, therefore, impossible.

TABLE 3.—FANN VISCOSITY IN CENTIPOISES OF HEAT TREATED BENTONITE AT VARIOUS TEMPERATURES (6% SOLIDS)

Heat-treat temperature, °F	Viscosity (centipoises)
Room temp.	20
510	17.5
870	4.0
1120	1.5

SUMMARY

The difference between sodium (western) and calcium (southern) bentonites and their reaction to heat have been shown. The evaluation made of their behavior in bonding foundry molding sand was established by the physical and mechanical properties they impart. Although both physical and mechanical properties could help to establish the mold-making ability of the aggregate, they cannot be used to predict the probability of making a defect-free casting. The end product of a foundry is a casting, not a mold. Discretion is needed, therefore, when applying the principles developed. It should not be taken for granted that an adequately bonded sand that will produce a good mold will necessarily produce a good casting.

Other tests developed to establish the mineralogy of bentonites, such as differential thermal analysis, viscosity, and melting or vitrification temperature, cannot be used by the foundry industry to check the suitability of bentonites, even from the bonding standpoint.

The conclusions reached are as follows:

1. The deterioration temperature of western and southern bentonite is 1180°F and 600°F respectively.

2. The drop in strength beyond the deterioration temperature is gradual for southern and abrupt for western.

3. The mulling response of heat-treated southern bentonite is substantially poorer than western and, at low mulling, the apparent deterioration temperature of southern is reduced.

4. Heating bentonites separately from the sands does not simulate the heating condition encountered in a mold.

5. The reaction of cereal to western bentonite remains unaffected at temperatures below 900°F. At 1120°F, however, there are indications that the cereal-bentonite combination starts to lose its ability to impart dry strength.

6. The riddled density of the sand can be used as a measure of flowability of sands and ease of mold densification.

7. Southern bentonite used as a bond in re-used sand, and without additives, yields more flowable sands than western-bonded ones.

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