Effect of High-Temperature Properties of Synthetic Molding Sands on Mold Quality

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ABSTRACT
In the present investigation, linear thermal expansion and deformation of different molding sand systems at various temperatures have been determined. The parameters: maximum thermal expansion, unaccommodated expansion, included area factor and critical temperature are determined from the experimental data. The mold quality is assessed by measuring scabbing time, which is related to critical pouring time for a given sand to avoid expansion defects. The sand systems are so formulated as to study the influence of bentonite, moisture, silica flour, grain size, inorganic clay, coal dust, dextrin, and wood flour. The complete experimental data is represented in four charts relating the abovementioned parameters and scabbing time. The investigations show that the parameters have a good correlation with scabbing time. Scabbing time decreases with increase in each of these parameters. The charts can be used to determine critical (maximum) pouring time for a given sand system. Further, given a pouring time, these charts can be used to formulate the sand systems which are least prone to expansion defects.

Introduction
The behavior of molding sands at casting temperatures is different from that at room temperature. To have a meaningful correlation between casting defects and the quality of molding sands, their properties should be determined at elevated temperatures. It is essential to identify those high-temperature properties of molding sands which are directly related and correlate with the defects, so that by determining them it is possible to predict or take corrective measures against their occurrence. Excellent reviews on high-temperature properties of molding sands have been reported by Rassenfoss, Morgan and Middleton. Hot compression strength, hot tensile strength, linear thermal expansion, force of expansion, hot deformation, wet tensile strength, and shear strength have been reported to be useful parameters which have correlation with casting defects.

AFS Sand Division Committee B has carried out extensive experiments to determine the high-temperature properties of natural and synthetic molding sands from various sources. Critical temperature, unaccommodated expansion and included area have been found to correlate well with the casting defects expressed as area of type A scrap defect. High values of these factors are associated with an increasing scabbing tendency. Although many sand systems show good correlation, some behave differently. For example, a few sand systems with high values of these factors have a very small scrap area or no defects at all.

In the present investigation, experiments have been carried out to determine the high-temperature properties of synthetic molding sands containing possible combinations of materials that are found in actual practice. Experimental techniques and the test specimen used — although different from those used by the AFS committee — represent the rapid heating conditions found in actual casting practice. The present aim is to 1) determine whether there is a correlation between the maximum thermal expansion, unaccommodated expansion, included area factor, critical temperature and mold quality; 2) determine which of these parameters show better correlation with the mold quality and 3) identify the sand systems which show good correlation and isolate those which do not show correlation. Such an analysis determines the significance of the parameters maximum thermal expansion, unaccommodated expansion, included area factor and critical temperature in relating to mold quality independent of the experimental technique, so long as the rapid heating conditions are maintained. It further provides information regarding the possibility of using the above parameters in formulating and processing sand systems which are least prone to expansion defects. Also, the identification of sand systems which show good correlation between the parameters and mold quality and those sand systems which do not correlate permits extra precautions to be taken while interpreting the experimental data during casting defect analysis.

Experimental Details
The following sand systems have been used in the present investigation:

1. silica sand M (avg grain size: 0.192 mm) + 6% bentonite B
2. silica sand M + 4% bentonite B
3. silica sand M + 8% bentonite B
4. silica sand M + 10% bentonite B
5. silica sand M + 6% bentonite B (25% compactability)
6. silica sand M + 6% bentonite B (55% compactability)
7. silica sand M + 6% bentonite B (60% compactability)
8. silica sand M + 6% bentonite B + 5% silica flour
9. silica sand M + 6% bentonite B + 10% silica flour
10. silica sand M + 6% bentonite B + 15% silica flour
11. silica sand M2 (avg grain size: 0.282 mm) + 6% bentonite B
12. silica sand M3 (avg grain size: 0.215 mm) + 6% bentonite B
13. silica sand M + 6% bentonite B + 3% inductive clay
14. silica sand M + 6% bentonite B + 6% inductive clay
15. silica sand M + 6% bentonite B + 9% inductive clay
16. silica sand M + 6% bentonite B + 3% coal dust
17. silica sand M + 6% bentonite B + 6% coal dust
18. silica sand M + 6% bentonite B + 9% coal dust
19. silica sand M + 6% bentonite B + 12% coal dust
20. silica sand M + 6% bentonite B + 0.5% dextrin
21. silica sand M + 6% bentonite B + 1.0% dextrin
22. silica sand M + 6% bentonite B + 1.5% dextrin
23. silica sand M + 6% bentonite B + 2.0% dextrin
24. silica sand M + 6% bentonite B + 0.5% wood flour
25. silica sand M + 6% bentonite B + 2.0% wood flour

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density of a standard AFS specimen with 3 rams. The small size of the specimen permits rapid penetration of heat by radiation that actually occurs in practice. The diameter of the specimen corresponds to approximately twice the thickness of the sand shell formed in the mold when it is subjected to radiation heat from molten metal. The properties of this layer are significant in the formation of expansion defects.

Measurement of Linear Thermal Expansion

The test specimen on a cylindrical silica disc is placed on the movable bottom compression post and raised until the convex silica cover disc placed on top of the sand specimen just touches the top fixed compression post in the apparatus. This position is set as zero reading on the strip chart recorder. The furnace set for a temperature of 1000°C (1832°F) is lowered onto the specimen and switched on. As the furnace temperature rises, the specimen gets heated up and the resulting expansion is continuously recorded on the strip chart recorder.

Measurement of Hot Deformation

The test specimen is placed between the compression posts of the apparatus. The furnace preheated to the desired temperature is lowered onto the specimen. The soaking time before the specimen is loaded in compression is determined from a calibration chart. This ensures that the specimen attains the desired furnace temperature before the test is carried out. As the specimen is loaded in compression, the deformation is continuously recorded. The maximum deformation before the specimen fails is determined at different temperatures.

Measurement of Scabbling Time

The mold quality is assessed in terms of scabbling time using the test piece proposed by Boenisch and Patterson. The details of the pattern and the assembled mold are shown in Fig. 2. The pattern is designed to provide an observation window through the cope surface to watch the spalling of sand layer under the influence of heat radiation. The mold is filled with molten metal to a depth of 15 mm in the drag, which is indicated with the help of a sand core. The sand core is located so that it can be observed through the window in the cope. The scabbling time is the time measured from the instant at which pouring begins to that at which the spalling of sand layer occurs. Scabbling time is a valuable index of mold quality. Higher scabbling time of a sand indicates its ability to permit longer pouring times to the practical foundrymen without causing expansion defects.

Test Results and Discussion

A typical graph showing expansion and deformation as a function of temperature is shown in Fig. 3. This figure refers to the sand system containing 6% bentonite, tempered to a compactability value of 50%. Such graphs have been plotted for all the sand systems used in this investigation. The maximum thermal expansion attained for the sand system is directly read from the graph as shown in Fig. 3. The difference between expansion and deformation values at 575°C (1067°F) is termed unaccommodated expansion and is expressed as a percentage. The area that is formed in the region of Fig. 3 where the deformation curve dips below the expansion curve is termed included area factor. The maximum temperature where expansion is first less than hot deformation is termed the critical temperature. The parameters maximum thermal expansion, unaccommodated expansion, included area factor and critical temperature for all the sand systems are determined from the plots similar to Fig. 3. The relationships between these parameters and scabbling time for the various sand systems are plotted in Fig. 4-11. The graphs are so drawn as to study the influence of variables such as bentonite, moisture, silica flour, grain size, inactive clay, coal dust, dextrin and wood flour.

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Influence of Bentonite

System sands may contain varying amounts of bentonite. Fluctuations can occur in the amounts of active clay content in recycled sands due to the thermal action of molten metal. Increasing additions of bentonite are usually made to molding sand to improve strength and to resist expansion defect tendency. In the present investigation, bentonite content is varied from 4-10%.

Figure 4 shows that with increase in bentonite content 1) scabbing time increases, 2) maximum thermal expansion decreases, 3) unaccommodated expansion decreases, 4) included area factor decreases and 5) critical temperature decreases.

Increasing additions of bentonite impart higher plasticity to the sand systems. Deformation is higher in the region where the sand expands, thus reducing unaccommodated expansion and included area factor. Decrease in the total expansion is due to higher shrinkage of clay film around the sand grains which limits the expansion of silica sand grains.

Influence of Moisture

System sands are tempered to varying degrees of compactability depending on the method of molding. Hand molders use a temper condition of 50% compactability, whereas machine molders use a slightly drier sand to have a greater flowability. In the present investigation, moisture in sands is varied from a dry temper corresponding to 25% compactability to a wet temper corresponding to 60% compactability.

Figure 5 indicates that with increase in moisture content, 1) scabbing time increases, although the increase is quite small, 2) maximum thermal expansion increases, 3) unaccommodated expansion decreases, 4) included area factor decreases and 5) critical temperature decreases.

Increasing amount of moisture content promotes denser packing of sand grains, which is reflected in increase in maximum expansion. However, deformation also increases resulting in a net decrease in unaccommodated expansion and included area factor. Also the denser packing may increase shear strength at the interface between the dry and moist layer when the mold is exposed to heat radiation.

Fig. 3. Typical expansion deformation — temperature curves.

Fig. 4. Influence of bentonite.

Fig. 5. Influence of moisture.
Influence of Silica Flour

Additions of silica flour are made to synthetic molding sands to reduce metal penetration. To simulate conditions that exist in practice, sand systems in the present investigation are formulated with silica flour additions from 3-15%.

Figure 6 shows that with increase in the addition of silica flour to 6% bentonite bonded sand systems, 1) scabbing time decreases, 2) maximum thermal expansion increases, 3) unaccommodated expansion increases, 4) included area factor increases and 5) critical temperature increases.

Addition of silica flour to the sand system increases its packing density, which is reflected in an increase in thermal expansion. It also increases rigidity of the sand mix, thus reducing deformation over the range of temperature in which the sand expands. This causes an increase in unaccommodated expansion and included area factor. A decrease in scabbing time shows that the influence of increase in expansion is higher compared to its influence on the strength at the interface between dry and moist layers when the mold is exposed to heat radiation.

Influence of Grain Size

Sands with finer grain size are used for foundries to improve the surface finish of castings and to reduce metal penetration. Fluctuations in grain size can also occur in system sands due to the entry of core sand into them at knockout and subsequent buildup with each cycle of operation. In the present experiments, the sands are formulated with average grain sizes of 0.192, 0.215 and 0.282 mm.

Figure 7 illustrates that with increase in grain size of 6% bentonite bonded sand system, 1) there is no appreciable

![Graph showing Influence of Silica Flour](image1)

![Graph showing Influence of Grain Size](image2)
variation in scabbing time, 2) maximum thermal expansion remains unaltered, 3) unaccommodated expansion decreases, 4) included area factor decreases and 5) critical temperature remains fairly constant.

The above observations indicate that within the range of variation in grain size investigated, expansion remains the same. Decrease in unaccommodated expansion with increase in grain size is due to the greater ability of coarser sand grains to rearrange themselves when they expand.

**Influence of Inactive Clay**

System sands in foundries contain a certain amount of inactive clay which is built up due to the thermal action of molten metal and repeated use of sands. To simulate the conditions that exist in practice, sand systems are formulated with 3, 6 and 9% additions of the same bentonite rendered inactive by heating at 900°C (1652°F).

Figure 8 shows that with increase in the amount of inactive clay present in 6% bentonite bonded sand, 1) scabbing time decreases, 2) maximum thermal expansion decreases, 3) unaccommodated expansion decreases up to 6% and increases with further increase in inactive clay, 4) included area factor decreases and 5) critical temperature decreases.

The above observations indicate the presence of inactive clay makes the sand system more plastic, although to a very large extent. Although the parameters maximum thermal expansion, unaccommodated expansion, included area factor and critical temperature are more favorable to have a high scabbing time, in fact, scabbing time decreases. This shows that spalling is influenced not only by properties of the dried layer but to a larger extent by properties of the interface between the dry and moist layer during heating.

**Influence of Coal Dust**

Coal dust additions are made to system sands in foundries to improve the surface finish of castings. In the present investigation, 6% bentonite bonded sands are given additions of 3, 6, 9 and 12% coal dust to simulate the conditions in practice.
Figure 9 illustrates that with increase in the addition of coal dust to 6% bentonite bonded sand, 1) scabbing time initially decreases and then increases with further additions, 2) maximum thermal expansion remains fairly constant, 3) unaccommodated expansion decreases and 4) critical temperature decreases.

The above observations indicate that coal dust appreciably alters characteristics of the dry sand layer. Decrease in expansion, unaccommodated expansion and included area factor is due to the volatilization of coal dust. However, scabbing time is not increased as it is to be expected. It shows that although coal dust additions have a desirable effect on the dry sand layer, they have undesirable effects at the interface between the dry and moist sand layers, causing early spalling.

**Influence of Dextrin**

Additions of dextrin are made to sand systems to improve their resistance to expansion defects. A series of experiments has been carried out on the sand systems containing 0.5, 1.0, 1.5 and 2.0% dextrin.

Figure 10 shows that with increase in the addition of dextrin to 6% bentonite bonded sands, 1) scabbing time increases, 2) maximum thermal expansion decreases, 3) unaccommodated expansion increases, 4) included area factor increases and 5) critical temperature increases to a small extent.

The observations indicate that the decrease in maximum expansion could be due to increase in plasticity and consequent ease in the rearrangement of sand grains. Increase in un-
accommodated expansion and included area factor can be explained by low deformation values at the time of failure. This occurs as the sand grains containing dextrin are very weak and the specimens fail at low deformation values although the rate of deformation is high.

Influence of Wood Flour

Wood flour is added to the sand systems to minimize expansion of its in synthetic molding sands. Experiments have been carried out to determine the properties of sand systems containing 0.5 and 2% wood flour.

Figure 11 shows that with increase in addition of wood flour to a sand system, 1) scabbing time is not altered appreciably, 2) maximum thermal expansion decreases, 3) unaccommodated expansion decreases, 4) included area factor initially increases and subsequently decreases with further increase in wood flour additions and 5) critical temperature increases at 0.5% addition and decreases at 2% addition.

Wood flour does not become plastic or liquid as do other additives such as coal dust and dextrin. However it alters the expansion characteristics as is seen from the above observations. Although wood flour addition has a desirable effect on the parameters, maximum expansion, unaccommodated expansion and included area factor, scabbing time is not altered appreciably. Thus it is seen that properties of the interface between the dry sand layer and moist layer play a more important role in spalling for sand systems containing wood flour.

To determine which parameter has a better correlation with mold quality expressed as scabbing time, data obtained for all the sand systems must be plotted in a single graph. The data is represented in Fig. 12-15 considering one parameter at a time. Fast filling of a mold is one of the most important considerations in minimizing expansion defects. The diagrams in Fig. 12-15 determine the critical pouring time for a given sand system. Or, if the critical pouring time has to be high from other considerations such as casting weight, it is necessary to formulate and process the sand system which can give higher scabbing time. Figures 12-15 are of significant value in this regard.

Figure 12 shows the relationship between maximum thermal expansion and scabbing time. Each sand system studied in this investigation is represented by a point on this diagram. Figure 12 shows that many sand systems have good correlation between maximum thermal expansion and scabbing time. Scabbing time decreases with increase in maximum thermal expansion. Sand systems containing inactive clay have low scabbing times, although they have low thermal expansion, thus falling out of regular correlation. While analyzing the casting defects, the data on scabbing time and the parameter thermal expansion permits prediction of the buildup of inactive clay in the sand system.

Figure 13 illustrates the relationship between scabbing time and unaccommodated expansion. A study of this figure shows that scabbing time decreases as unaccommodated expansion increases. Most of the sand systems show a good correlation except those containing dextrin. These sand systems have a high

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Fig. 12. Relationship between thermal expansion and scabbing time.

Fig. 13. Relationship between unaccommodated expansion and scabbing time.
scabbing time although they have a high unaccommodated expansion factor. In formulating the new sand systems which are least prone to expansion defects, this diagram is useful.

Figure 14 illustrates the relationship between scabbing time and included area factor. This figure shows that some sand systems have good correlation between scabbing time and included area factor. However sand systems containing inactive clay, coal dust and dextrin behave differently. Sand systems containing inactive clay and coal dust have a low scabbing time although their included area factor is low. Care must be exercised when interpreting the results using this diagram when the sand systems contain these components. Sand systems containing dextrin have a high scabbing time although they have a high included area factor. During casting defect analysis, determination of scabbing time and included area factor permits the presence of these components to be identified.

Figure 15 shows the relationship between scabbing time and critical temperature. This figure indicates that except for the sand systems containing coal dust and dextrin, others show a correlation between scabbing time and critical temperature. By determining critical temperature, it is possible to estimate maximum pouring time using the particular sand system.

Conclusions
1) Maximum thermal expansion, unaccommodated expansion, included area factor and critical temperature are significant parameters related to scabbing time which is an index of mold quality. Scabbing time decreases with increase in each of these parameters.
2) Unaccommodated expansion and maximum thermal expansion have better correlation compared to included area factor and critical temperature with scabbing time.
3) Charts showing the relationships between the parameters unaccommodated expansion, maximum thermal expansion, included area factor and critical temperature can be used to determine the critical (maximum) pouring time for a given sand system.
4) Given a pouring time which is decided considering the weight of casting, the charts can be used to formulate sand systems which have a suitable critical scabbing time.
5) Care must be exercised in interpreting data on sand systems containing inactive clay, coal dust and dextrin.
6) During casting defect analysis, by determining the parameters and scabbing time and using the charts, the presence of inactive clay, coal dust and dextrin can be identified. This is possible by observing their deviation from regular correlation.

References