Investigation into the Technical Limitations of Silica Sand Due to Thermal Expansion

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ABSTRACT

Casting defects that are a result of the thermal expansion of silica sand have always posed difficulties for the metal caster. Veining, scabs, rattails and castings out of dimensional tolerances are only a few of the defects that are associated with the detrimental expansion silica sand. The following study was funded by multiple member companies of the National Industrial Sand Association. The study reviewed how the expansion of sand had previously been tested and covers the development of new testing equipment to increase sensitivity and accuracy of the results. The new equipment was utilized to measure the expansion of loose unbonded silica sands with relation to mesh size, grain shape, screen distribution, chemistry and density. The study also investigates the influence of chemical binder systems including phenolic urethane cold box, ester cured phenolic, furan and modified sodium silicate on the thermal expansion of bonded sand samples. The study also investigated the expansion of bonded sands with additives that included red iron oxide, black iron oxide and engineered sand additives.

INTRODUCTION

This is a report of a study initiated and sponsored by the National Industrial Sand Association (NISA) at the University of Northern Iowa (UNI) to assist the industrial sand and foundry industries to understand how the properties of silica sand and additives contribute to expansion and develop accurate information about thermal expansion of silica sand. Thermal expansion of sand can be defined as an increase in linear dimension of a sand mixture accompanying a change of temperature. The goal of this project was to develop test methodology for measuring raw sand expansion, and apply the methodology to measurement of both unbonded and bonded sands in order to better understand and minimize the effects of silica sand expansion.

EXPANSION AND VEINING

Foundries have historically associated certain casting defects with sand expansion. In green sand they have included scabs, buckles & rattails; and in core sand the defects have concerned veining, fins and dimensional problems. Sand is only one of the many considerations when looking at expansion. It is the largest volume of material in the mix, but it is only part of the mixture of sand with binder and additives. The expansion of each material in combination with the metal and other materials and the variables in the process all need to be understood. Veining is an important expansion defect in foundries that causes considerable re-work and scrap. Veining primarily occurs at the core sand surfaces. It is not as prevalent in green sand applications. The main difference in the two systems is the mixture. The sand is the same, but the binder and additives by percentage and type are very different. Metal heats up the core surface and depending on many variables, the core may or may not prematurely crack open and allow metal to flow into an area causing a fin. The ability of heat to transfer through the core sand will determine if, and to what degree, a change will take place.
INFLUENCING FACTORS

Previous research has shown us that factors that influence veining include sand distribution, percentage and type(s) of binders, density, compaction, head pressure, temperature, pouring times, casting design, additives, and core wash.

There is overwhelming evidence that this list of factors can contribute to or reduce veining. Various types of sand such as silica, lake, olivine, chromite and zircon can have different expansion rates. Most binders will start to change in the presence of heat long before the first phase change of silica. As a result, the percentage and type of binder that is utilized can produce different expansion rates. The density and compaction of the core can in part determine the heat transfer through the mixture as the metal is poured and solidifies. High compaction and density will provide tighter grain-to-grain contact. High head pressures, temperatures and slow pouring times can promote veining. We definitely can design castings to promote veining. Metal thickness and solidification rate in key areas of the casting certainly can contribute to core sand expansion. Core washes and additive provide aids to reduce or prevent veining. Additives can change the core sand expansion rate and wash can provide a barrier to resist heat transfer.

The chart in Table 1 has existed for many years and was included in the old American Foundry Society (AFS) Core & Mold Test Handbook. The problem with this and other expansion-related charts is that it is very general and much information is missing! Binders were utilized, but the amount was not indicated nor the type. All previous expansion-testing equipment was set up for bonded samples. The most important aspect of the chart is the silica category. We know that the silica curve includes a wide range of silica content, which does not appear appropriate.

The literature search and investigation by the authors of this paper did not find any information on how the origin of this chart, nor does it provide sufficient information to allow one to understand the expansion between sand types, distributions or purities. There was no information on the methodology utilized. Much of the original expansion work was performed in the 1930s because of green sand expansion problems. As a result, clay-bonded samples may have been used to produce the information, which, if true, would impact the results significantly.

Table 1 is a condensed version of the table, which accompanied the chart in Figure 1. Under the category “silica,” lake type sands are included. This is clear if we look at the description following each property. The work referenced in this paper confirms the difference in expansion between lake and other silica sands. They cannot be lumped together.
The authors have used the terms below to clarify terms such as “silica,” “lake,” “bank” and “river” sands. These terms are described in Table 2 with corresponding photographs of the sands shown in Figures 2 through 4.

NEW DEFINITIONS OF FOUNDRY SAND

<table>
<thead>
<tr>
<th>New Designation</th>
<th>Old Designation</th>
<th>Silica Content</th>
<th>Grain Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSSA Low Silica Sub</td>
<td>Lake Sand</td>
<td>94-96%</td>
<td>Sub-Angular</td>
</tr>
<tr>
<td>- Angular</td>
<td>Bank Sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dune Sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSSA High Silica Sub</td>
<td>New Jersey Silica Sand</td>
<td>98% +</td>
<td>Sub-Angular to Angular</td>
</tr>
<tr>
<td>- Angular</td>
<td>East Coast Sub-Angular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSR High Silica Round</td>
<td>Silica Sand Round Grain</td>
<td>98%+</td>
<td>Round</td>
</tr>
<tr>
<td></td>
<td>St. Peters Deposit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2 Sand Designations**

**HISTORY OF SAND EXPANSION**

Prior to the work done by H.W. Dietert and F. Valtier, which was published in the 1935 American Foundrymen's Association (AFA - forerunner of AFS) Transactions, little had been done to quantify the behavior of foundry sand at elevated temperatures. The Dietert and Valtier paper revealed the expansion and contraction characteristic of clay-bonded silica sand as it was heated and cooled in their high temperature dilatometer; this paper spurred a huge amount of interest and subsequent research on the subject. The development of elevated temperature testing equipment and techniques resulted in significant advances in the understanding of the behavior of foundry sand at casting temperatures. This information was a revelation to foundrymen at the time since it began to explain the behavior of molding sand at near casting temperatures and tied the test results to common casting defects such as rat-tails (veining) buckles, and scabs, etc. The Dietert and Valtier paper spurred elevated temperature research on foundry sand for the next 35 years.
In the late 1930s the AFA worked with the U.S. Naval Research Laboratory to investigate further “The Physical Properties of Steel Sands at Elevated Temperatures.” This work was supervised by AFA Committee 8-L and was conducted at Cornell University, Ithaca, NY, beginning in late 1937, and was sponsored by AFA/AFS until finished in 1957. The research resulted in the publication of thirteen research reports and a summary report in 1955\textsuperscript{4-18}. While AFA Committee 8-L was pursuing research on steel sand properties at elevated temperatures, Committee 8-J was formed to investigate elevated temperature performance of iron foundry sands. Committee 8-J was very active and had a more “hands-on” approach as the members held the Committee’s meetings at various foundries and laboratories, where they would conduct the actual testing. Committee 8-J produced eight research reports\textsuperscript{19-26} 1946-1955; six on the subject of clay bonded sand and two on veining characteristics of cores.

Research conducted by Riggan, Albus and Pragoff\textsuperscript{27-28} was published in the AFA Transactions in 1942 and 1943, and opened up organically-bonded (core) sand as a new direction of elevated temperature sand testing. However, since the core sand specimens burned and disintegrated very quickly upon exposure to high temperatures in an air atmosphere, the information that could be learned was limited. To address the problem of core sand samples exposed to an air atmosphere during elevated temperature testing, Dietert and Doelmann\textsuperscript{29} developed the “own atmosphere” accessory for use in their high temperature dilatometers. This accessory allowed sand specimens to be tested while minimizing the effect of being exposed to an oxidizing atmosphere (air). While not perfect, the “own atmosphere” accessory allowed study of the elevated temperature characteristics of organically bonded sand (cores), with much improved results. During the mid-1950s, Dietert, Rowell, and Graham \textsuperscript{30} developed the sand expansion micrometer, which provided a more convenient method for obtaining sand expansion data compared to the previously used vertical measurement method. The sand expansion micrometer also eliminated the “self loading” effect, in which the weight of the sand specimen itself affects the expansion results when tested vertically. Unfortunately, the sand expansion micrometer was more useful for studying the thermal expansion of clay-bonded sand mixtures than organically-bonded core sand, since it did not incorporate the “own atmosphere” concept. During the “golden age” of elevated temperature sand research (1935-1970) only four technical papers were written that specifically addressed organically-bonded cores\textsuperscript{24, 25, 28, 31}. Again, this was due to the difficulty of testing organically-bonded sand specimens with the available equipment and methods.

The elevated temperature sand testing equipment and methods used today date back to the mid-1950s. Most of the work concerning elevated temperature testing of foundry sand took place between 1935-1970, with a comparatively small amount of work in subsequent years. Most of the elevated temperature research focused on clay bonded molding sand, since the available equipment and methods lent themselves to sand that did not disintegrate at high temperatures upon exposure to air, as is the case with organically bonded core sand. Despite all the research work conducted on elevated temperature testing of foundry sand from 1935 to present, no work has ever been published on measurement of the thermal expansion of unbonded sand.

As J.A. Rassenfoss said in his 1971 AFS Silver Anniversary Lecture\textsuperscript{32}, Elevated Sand Testing 1935-1971, “From this perspective, it is apparent that many early workers had adopted the correct theory to explain sand mix behavior, but failed to convincingly prove the accuracy of their conclusions because of the inability of their methods and apparatus to accurately measure the desired values. Later investigators with better apparatus were able to prove these theories beyond doubt. As new and better equipment is developed more work should be done to advance sand technology.”

The lack of data on the elevated temperature performance of unbonded sand is most likely due to the unavailability of appropriate equipment and methods to allow the thermal expansion of unbonded sand to be measured. It is our belief that studying the elevated temperature behavior of unbonded sand may hold the key to understanding why foundry sand performs the way it does at the most basic level. Expansion has been blamed for casting defects. For this reason it is important to determine an accurate rate of expansion on unbonded material. Foundry practices have changed greatly through the years and expansion testing equipment and methods have not caught up with the binder technology. To address the problem of measuring the thermal expansion of unbonded sand, NISA and the University of Northern Iowa’s Metal Casting Center decided to design and build an updated dilatometer, capable of accurately measuring the thermal expansion characteristics of unbonded sand.

**DESIGN OF DILATOMETER**

To enable us to study the thermal expansion of bonded sand as well as unbonded sand samples, a dilatometer needed to be designed and built with those capabilities. The dilatometer was designed robustly to provide the temperature range and degree of accuracy required. This was accomplished by the testing methodology and ability to process the raw data from the unit to achieve the required information. Because the samples are un-bonded they need to be contained in a crucible for
testing. Other parts of the dilatometer designed to hold the sample include pieces such as the sample tube and the pushrod which actuates the linear variable displacement transducers (LVDT). The crucible, pushrod or sample tube also expands each time regardless of what type of sand is being tested. The ceramic material chosen for these items was alumina (Al₂O₃) with a known coefficient of thermal expansion (CTE) of around 5.4 ppm/°C, which is the same as the fused quartz used in the conventional horizontal free expansion test equipment. The Al₂O₃ gives us a higher service temperature limit on the unit and is considerably more durable. Even though the expansion of the alumina sample holder is minimal, we increased the accuracy of the test results by processing the data mathematically to correct for the thermal expansion of the pushrod and sample holder combination. A correction factor was also applied to the results to compensate for the volumetric growth of the containment crucible due to thermal expansion. Figures 5 and 6 illustrate the construction of the dilatometer.

![Figure 5 General layout of Dilatometer](image)

![Figure 6. Screen layout of dilatometer](image)

**TESTING OF UNBONDED SAND**

This phase of the project investigated the influence of three main factors, mesh size, silica content, and shape. These were examined on individual mesh sizes for Wisconsin high silica round grain (HSR), three Illinois HSR sands, Michigan low silica sub-angular (LSSR) sand, and high silica sub-angular sand (HSSA). Additional testing was conducted to determine the influence of the AFS-Grain Fineness Number (GFN) of commercially available silica sands tested. Of the six sands that were tested, three were split into individual mesh sizes. Chemical analysis for the individual mesh sands was submitted by the companies providing the sand samples to allow analysis of the influence of trace elements on the thermal expansion of the sands. Each sand sample was run multiple times to verify the validity of the thermal expansion data.

The literature search revealed very little information about how the base characteristics of unbonded silica sand (grain size, grain shape, particle size distribution, purity level) affected the sand’s thermal expansion. Most if not all the published data on expansion of foundry silica sand had been developed from sand mixtures bonded with western bentonite. Although these data are valuable in determining overall expansion levels of various silica sands, they do not provide any information on silica sand expansion when combined with various, non-bentonite binder systems. The ability to obtain the thermal expansion profile of unbonded sand has yielded specific information about the base characteristics of the various commercial grade silica sands commonly used in the metal casting industry today.

In order to fully understand the thermal expansion characteristics of the various unbonded silica sands used in the research study, the effect of several man-made particle size distributions was also investigated along with source, shape and chemical purity of the sand. These tests included:

1. Influence of Individual Mesh Size (“Individual mesh size” refers to the use of USA Standard sieves (#20, #30, #40, #50, #70, #100, #140, #200, #270) to obtain a narrow grain size range; i.e., “50 Mesh” would be defined as the sand grains that will pass through a #40 sieve and be retained on a #50 sieve.
2. Influence of silica content on peak expansion
3. Influence of sand shape on peak expansion
4. Influence of sand density
5. Influence of Screen Distribution
INFLUENCE OF INDIVIDUAL MESH SIZE

The testing showed a good correlation between the individual mesh size and the peak expansion of the sands. This relationship showed a correlation coefficient of 0.75 indicating that the finer the mesh size the lower the peak expansion. This relationship was true for HSR as well as LSSA sand. An interesting point was that when the 70 and 100 mesh was removed from the analysis the correlation coefficient increased to 0.85. The 140 mesh showed some of the lowest overall expansions. These results are illustrated in Figure 7. The testing also had showed that in general, the finer the AFS-GFN of the sand, the lower its peak thermal expansion, as illustrated in Figure 8.

Figure 7. Sand expansion as a function of mesh size. Figure 8. Expansion as a function of AFS GFN.

INFLUENCE OF SILICA CONTENT

Sands with differing silica contents were tested to determine the effect on peak expansion. The testing showed that chemistry was the largest single influence in the expansion of the sand. Figure 9 compares high purity sub-angular silica (HSSA) sand with a Michigan LSSA sand. The same effect is seen in Figure 10 when we compare Michigan LSSA sand with high silica round grain (HSR) sands.

Figure 9. Influence of silica content on 70 Mesh sands. Figure 10. Expansion as a function of silica content and shape.

INFLUENCE OF SAND SHAPE

The shape of the sand did not seem to affect the peak expansion of the sands. This is illustrated in Figure 11 and compares HSSA sand with a high purity round grain (HSR) sand.
INFLUENCE OF SAND DENSITY

The density of the samples failed to correlate with the peak expansion. All of the unbonded samples used in the analysis were fully densified by weighting and vibrating the samples to a constant volume. The individual mesh size samples of HSR and LSSA sands both compacted to 1.64 g/cm³. If unbonded sand density has any relation to thermal expansion, the current sample compaction method negates any measurable difference between sand types. This finding is consistent with the lack of correlation found between the sand density and peak thermal expansion.

INFLUENCE OF SCREEN DISTRIBUTION

A particular sand’s particle size distribution has been known to have an effect on the density of cores and molds and has been thought to increase expansion with increasing density. Sizing of the sands has been shown to have a direct affect on the peak expansion. An Illinois HSR was screened, using USA standard sieves to separate particles on individual mesh sizes. These single mesh sand samples then were used to construct modified or non-normal sand distributions to determine the effect on the base expansion of un-bonded samples. Table 3 lists the various particle size distributions used during this part of the thermal expansion testing.

![Figure 11. Influence of sand shape on peak expansion.](image)

Table 3 Modified Screen Distributions Percent Retained.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Skew Right</th>
<th>Skew Left</th>
<th>Bi-modal</th>
<th>Flat</th>
<th>Narrow</th>
<th>Control</th>
</tr>
</thead>
<tbody>
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<td>0</td>
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<tr>
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<td>5</td>
<td>11</td>
</tr>
<tr>
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<td>50.26</td>
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<td>50</td>
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</table>

Densities for the samples are listed in Table 4. Densities ranged from a low of 108.45 lbs/cuft in the control sample to 123.50 lbs/cuft in the bi-modal distribution. This may indicate that non-normal distributions such as bi-modal may be useful in
situations where maximum density is needed. One such situation may be the prevention of metal penetration defects. In a similar manner skew left distributions may offer superior surface finish to a normal distribution. Each of the non-normal distributions was tested for unbonded sand expansion. The results were surprising in that all the distributions had a similar expansion rate (see Figure 12). Once again we had seen that the sand density did not affect the peak or rate of expansion of the silica sands. This is contrary to what we have seen published in the literature and what has been conveyed to sand users in the metal casting industry. What this could mean to sand suppliers to foundries is that they can modify the screen distributions and density or fineness of their products without a concern for an increase in expansion related defects. Other considerations with permeability or surface area and binder requirements may still limit how much we can modify these distributions. Step cone results are shown in Table 6.

### Table 4. Densities of Modified Screen Distributions

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Skew right</th>
<th>Skew left</th>
<th>Bi-modal</th>
<th>Flat dist.</th>
<th>Narrow dist.</th>
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<tbody>
<tr>
<td>Loose density</td>
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<td></td>
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<tr>
<td>lbs/ft³</td>
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<td>102.53</td>
<td>102.36</td>
<td>102.25</td>
<td>99.97</td>
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<tr>
<td>Tapped density</td>
<td>108.45</td>
<td>106.01</td>
<td>104.07</td>
<td>123.50</td>
<td>111.34</td>
<td>103.96</td>
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</tbody>
</table>

Since no significant difference in thermal expansion was detected due to sand density, it was decided to look at finer sands. Table 5 illustrates these finer sand screen distributions. The thermal expansion results are shown in Figure 13.

### Table 5. Finer Sand Screen Non-Normal Screen Distributions

<table>
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<tr>
<th>Sieve Size</th>
<th>Skew Right</th>
<th>Skew Left</th>
<th>Bi-modal</th>
<th>Flat</th>
<th>Narrow</th>
</tr>
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<tr>
<td>Pan</td>
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<td>0</td>
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<tr>
<td>AFS GFN</td>
<td>62</td>
<td>83</td>
<td>65</td>
<td>69.5</td>
<td>70</td>
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</table>
It should be noted that the further the peak expansion is to the right, the higher the casting ranked for expansion-related defects. The step cones were evaluated using a numerical ranking system developed by the university. Each of the rings of the step cone casting is evaluated separately and given a numerical value. These values are then totaled and compared with other test casting results. Figure 14 illustrates a step cone core and resulting casting. An example of the ranking is shown in Table 7. The ranking of the test castings may indicate that the peak expansion is not as influential as the temperature at which it expands. This finding warrants further investigation of the heat transfer of sand blends.

**EFFECTS OF FOUNDRY RESINS**

The initial work in the area of bonded sand testing has shown us that the expansion characteristics vary greatly compared to that of the unbonded aggregates. Some of this is explained by the organic nature of most binders in which the binder is decomposing or burning off the sand grains while the sand is heated. An additional effect of the binder is thought to be the further polymerization of the binder during the early stages of heating. This combination of decomposition and further polymerization has added a large amount of noise to the measurement of the expansion of the bonded sands. While it has been relatively easy to produce consistent samples in unbonded sands, it appears to be much more difficult to produce a consistent sample in the bonded state. Because of the great extent of influence the binder has on the expansion of the sample, even minor changes in the resin level may have major effects on the expansion profile.

Figures 17 -19 show the three main types of sands bonded with phenolic urethane cold box (PUCB) binder system. Figure 17 shows LSSA bonded with PUCB at three binder levels from 1.0-2.0%. We can see that at all binder levels the PUCB binder decreases the expansion of the silica sand. It was also observed that the expansion of the samples increased proportionally to the amount of binder used. The LSSA samples exhibited a slight secondary peak after the maximum peak expansion. The reason for this secondary peak is unknown but may be the cause of reduced veining seen in LSSA test castings.
Figure 18 shows the HSR bonded with PUCB binder at three levels. The expansion at all bonded levels is lower than the unbonded expansion. The 1.0% binder level showed the highest expansion of the bonded samples. The PUCB binder seemed to have less of an effect on the HSSA samples. The 1.0% bonded samples were only slightly lower in expansion as the unbonded sample. Expansion seemed to decrease with increasing levels of binder contrary to the results for the LSSA. Both the LSSA and the HSSA exhibited lower peak expansions than the HRS sands at all binder levels.

The next group of samples was bonded with the ester cured phenolic binder system. These are shown in Figures 20-22. The LSSA and HSSA samples showed a secondary peak or flattening of the contraction side very similar the LSSA samples bonded with PUCB. This is interesting since the ECP bonded cores are known to exhibit fewer veins in casting. The LSSA samples showed very little contraction between 1100 and 2000°F. The HSR exhibited more contraction for the temperatures between 1100 and 2000°F.

The furan bonded samples are shown in Figures 23-25. The presence of binder on the sand grains did not seem to change the overall expansion peak as was evident in the PUCB samples with the LSSA and HSR sands. The HSSA sands showed increasing expansion directly proportional to the binder content. The samples bonded at 2% showed almost a .5% increase in peak expansion although the significance of this increase is not fully understood. There were no secondary peaks in any of the samples observed.

Figures 26-28 show the three sand types bonded with the sodium silicate binder system. These samples were blown and cured with CO2 gas. The amount of binder did not seem to change the peak expansion in any of the samples. All of the samples exhibited a secondary expansion at approximately 2020-2040°F. The peak of this secondary expansion was not revealed at the time of testing.

SUMMARY OF PHASE IV CONCLUSIONS
1) In some cases PUCB binders decrease the amount of expansion of silica sands
2) Binders may interact with silica sand to cause a decrease in contraction after peak expansion
3) Binders may interact with silica sand to cause secondary expansion peaks
4) Secondary expansion peaks are an indication of reduced expansion

HOW EXPANSION RELATES TO VEINING DEFECTS

As veining is the largest single defect associated with the thermal expansion of silica sand, it was decided to determine the level of expansion at which the veining defect would occur in a step-cone test casting. In order to accomplish this we had to evaluate the veining tendencies of the core sand mixture from the lowest to highest thermal expansion we could expect of silica sand. In order to reduce the amount of expansion of the sand core we needed to blend the silica sand with a material with a low expansion material (LEM). Using the law of mixtures we produced a series of silica sand and LEM core sand mixtures which allowed us to control the resulting thermal expansion and determine if there was a threshold expansion value where veining would begin to occur. Expansion values of the LEM silica sand blends are shown in Figure 15.

Each of the mixes was tested to evaluate its total expansion. The results are shown in Figure 16. As the law of mixtures had predicted, the expansion of the mixture of silica sand and LEM showed a straight line relationship between percentage of LEM and expansion of the mixture. This indicates that there was no synergistic effect of the LEM to the silica sand. The results of the step cone testing for veining tendencies were unexpected. It was expected that the 100 percent LEM core would not exhibit any veining. It was also expected that the 100 percent silica sand core would exhibit some level of veining. This was verified by the casting test. What was not expected was that there was no clear threshold value where veining stopped. Table 7 shows the evaluation of the castings and their respective ranking due to the veining defect. We can see by the ranking that as the percentage of LEM increases so does the rank of the casting. The higher the value for each ring on the step cone casting the more veining it represents. We should note that the step cone castings with any silica sand in the mixture exhibited some level of veining defect. This may be explained in Figure 16 which shows not only the expansion of the silica LEM mixtures but the first derivative of the expansion curve. The 1st derivative of the expansion curve is the rate at which the sand expands. Typically the temperature at which the sand expands the most is the change from lower quartz to upper quartz at or around 1062°F.
Table 7 Ranking Results of Step Cone Casting Evaluation

<table>
<thead>
<tr>
<th>% LEM</th>
<th>Ring 1</th>
<th>Ring 2</th>
<th>Ring 3</th>
<th>Ring 4</th>
<th>Ring 5</th>
<th>Ring 6</th>
<th>Index</th>
<th>Rank#</th>
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<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
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<td>2</td>
<td>46</td>
<td>7</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>28</td>
<td>6</td>
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<td>2</td>
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<td>21</td>
<td>4</td>
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<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 15. Expansion of the silica LEM mixtures

This point accounts for over 75% of the typical expansion seen in silica sand between room temperature and 2000F. Through the use of the first derivative we can see easily the peak expansion rate at the peak on the graph. We also noticed that the temperature at which this peak expansion was exhibited did not change as long as silica was in the sand. This peak in expansion rate corresponds well with the casting exhibiting veining defects and may well be a very good indication of veining in core sands. We observed that only the 100% LEM exhibits the total absence of veins. This may indicate that the extent of the expansion may not be the determining factor, but rather the timing in which this peak expansion is exhibited. Further work is needed to determine if delaying the peak expansion as little as 100F can reduce or eliminate veining defects.

SUMMARY OF THE AFFECTS OF FOUNDRY RESINS
1) Finer mesh sands expand less than coarse
2) SiO2 content seems to have the greatest effect on expansion
3) Grain shape has little effect on sand expansion under maximum compaction
4) Screen distribution has little or no effect on sand expansion
5) The temperature the sand expands may have more effect on veining than the magnitude of expansion
Comparison of Bonded Sand Expansions
(LSSA Bonded with PUCB)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Comparison of Bonded Sand Expansions
(HSR Bonded with PUCB)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Comparison of Bonded Sand Expansions
(HSSA Bonded with PUCB)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Comparison of Bonded Sand Expansions
(HSR Bonded with ECP)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Comparison of Bonded Sand Expansions
(HSSA Bonded with ECP)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Comparison of Bonded Sand Expansions
(LSSA Bonded with ECP)

-0.0020 0.0000 0.0020 0.0040 0.0060 0.0080 0.0100 0.0120 0.0140 0.0160

Temperature F

Figure 17. Expansion of LSSA bonded with PUCB.

Figure 18. Expansion of HSR bonded with PUCB.

Figure 19. Expansion of HSSA bonded with PUCB

Figure 20. Expansion of LSSA bonded with ECP

Figure 21. Expansion of HSR bonded with ECP

Figure 22. Expansion of HSSA bonded with ECP
Comparison of Bonded Sand Expansions

Figure 23. Expansion of LSSA bonded with FNB

Figure 24. Expansion of HSR bonded with FNB

Figure 25. Expansion of HSSA bonded with FNB

Figure 26. Expansion of LSSA bonded with Sodium Silicate

Figure 27. Expansion of HSR bonded with Sodium Silicate

Figure 28. Expansion of HSSA bonded with Sodium Silicate
THE EFFECT OF ADDITIVES ON THE EXPANSION OF BONDED SAND SAMPLES

Red iron oxide (RIO) and black iron oxide (BIO) were added at a level of 3% and an engineered sand additive was added at a level of 7%. These addition levels were consistent with industry standard practices and manufacturer recommendations. All of the samples included in this group were produced with a binder level of 1.5% to limit the number of samples required.

Figures 29-31 show the PUCB bonded samples with three additives. Both RIO and BIO showed contraction after peak expansion but this contraction seemed to be delayed almost 400F. The samples that contained the engineered sand additive showed major expansion after 1600F. This expansion equaled as much as 5% in the samples.

Ester Cured Phenolic (ECP) bonded samples with additives are illustrated in Figures 32-34. All of the additives seemed to decrease the amount of contraction after peak expansion was observed. The engineered sand additive caused a secondary expansion peak around 1950F. This was consistent through all of the sand types but considerably less at a maximum of .300in/in than the .600in/in obtained in the PUCB samples.

Figures 35-37 show the Furan No-Bake (FNB) bonded samples with additives. All of the additives appeared to decrease the 1062F peak expansion of the samples. All of the samples exhibited reduced contraction between the 1062 and 1500F temperature ranges. Samples that contained the engineered sand additive showed a typical secondary peak between 1900 and 2000F.

Sodium silicate-bonded samples with the additives were shown in Figures 38-40. Both the RIO and BIO seemed to have little effect on the expansion characteristics of the samples. The ESA had a similar effect as in the previous binder types but the peak expansion was suppressed to a point just above the original quartz transformation point. The BIO and RIO both appeared to have a late 2250F secondary expansion peak.

It should be noted that the unbonded sand expansion values have been adjusted to compensate for the three dimensional expansion. The following graphs should show the true relationship between bonded and unbonded sand samples. In all cases the bonded sand samples show a lower expansion level. The level of expansion seems to correlate well with the binder content of the samples with the exception of the sodium silicate-bonded samples. The LSSA sand samples bonded with PUCB seem to show a secondary reaction. This may be the result of small amounts of natural contaminants in the sand and will need to be investigated further.

SUMMARY OF THE AFFECTS OF ADDITIVES
1) Peak expansion was not affected by the addition of red or black iron oxide
2) Red or black iron oxide additions seemed to decrease the amount of contraction after peak expansion and appeared to cause some secondary expansion peaks
3) Engineered sand additives seemed to have the greatest affect on the presence of secondary expansion peaks
4) It was felt that minimizing the contraction and or the presents of secondary expansion was the factor responsible for the decreased veining defects
Comparison of Bonded Sand Expansions with Additives

(HSSA Bonded with PUCB + Additives)

Figure 31. HSSA bonded with PUCB with additives

(HSSA Bonded with ECP + Additives)

Figure 32. LSSA bonded with ECP with additives

(HSR Bonded with ECP + Additives)

Figure 33. HSR bonded with ECP with additives

(HSSA Bonded with FNB + Additives)

Figure 35. LSSA bonded with FNB with additives

(HSR Bonded with FNB + Additives)

Figure 36. HSR bonded with FNB with additives
CONCLUSIONS

For years foundrymen and researchers alike have blamed veining defects on detrimental effects of the expansion of silica sand. It was well known that silica exhibits a sharp expansion at approximately 1063°F due to a change in crystalline structure from alpha to beta quartz. This change in volume causes difficulties in producing dimensionally accurate castings and often is associated with the casting defect of veining. Previous attempts at measuring this expansion failed to accurately identify specific characteristics in the expansion, and concentrated on the peak or overall expansion. Because of advancements in measurement technology we now can get a much better understanding of the expansion characteristics of silica sand and additives used in foundries and the formation of certain related defects in these materials.

In this study, an advanced measurement system was developed for the testing of silica sands specifically in the unbonded state. The test methods used technology that was not available when the original tests were conducted. This new technology allowed the measurement of the expansion signature of silica sand more accurately than had ever been accomplished before. With this additional information we were able to study the effect of changing various characteristics of the sands in an attempt to minimize their expansion.

We were able to make a number of observations. Mesh size had a minimal effect of the expansion of the sand, but showed that all sands are not created equally. As a result of the testing we determined that the smaller mesh sizes expanded less that the larger mesh size sands. This finding held true to a lesser extend when looking at commercial multi-screen sands. The finer the sand, the less it would expand. Test castings showed that the lower expansion of the finer sands also had a positive effect on the number and severity of the veining defects. When it was determined that we could artificially change the expansion of the silica sands, the research turned to additional methods of changing the screen distributions from normal to man-made distributions. The results were interesting. Although we could manipulate the screen distributions to increase the
density, the peak expansion and corresponding veining were not drastically changed. This discounted the long-held belief that sand density is one of the significant variables to the amount of expansion sand undergoes through heating.

Through the testing and observation of various types of sands, one characteristic did prove a significant variable. As the sands were heated, they would expand slowly until they reached the point where the alpha quartz would change to beta quartz. This change was accompanied by an abrupt change in volume. Immediately after the sand reached its peak volume, it began to contract. This contraction ranged from as much as 1% to a low of .3%. When bonded samples were tested, the contraction remained. Some of the binder sand combinations showed a reduced amount of contraction or, in some specific conditions, a small secondary peak after the original alpha to beta quartz transformation.

Up to this point we always had thought of veining defects as relating to the peak expansion of the silica sands. To prove this we looked for a critical peak expansion value under which veining defects would not occur. What we found was that there was no level of expansion that would yield a casting free of veining defects. We found that veins occurred not from the peak expansion but from the rate of contraction that occurred immediately after peak expansion. In other words, no matter how low the peak expansion was we still would have veining defects in test castings. This was explained by what we had seen in the previous samples and the contraction of the sands, both bonded and unbonded. Sands that showed a reduced contraction and or a secondary expansion yielded fewer veins when used in test castings.

When additives of red iron oxide, black iron oxide and engineered sand additives were used in the bonded sand samples, the contraction was reduced or secondary expansion peak increased. The oxides showed a secondary peak in some of the binder systems around 1500 to 1700F, whereas the engineered sand additives showed a very large secondary expansion at approximately 2000F. The peak of the secondary expansion of sand which contained engineered sand additives showed a total expansion of approximately 5%. This was three times the expansion seen in bonded silica sand alone. The ESA was run in the unbonded state and showed similar results indicating that the additive was acting on the sand and not the binder. This fact led the research team to the conclusion that the contraction of the silica sand that occurred after the initial alpha to beta expansion had caused the defects. Additives in common use in the foundry industry either reduced this contraction or caused a secondary expansion before the metal was solidified.

REFERENCES

1. AFS Mold & Core Test Handbook, 2nd Edition