International Journal of Thermophysics, Vol. 26, No. 1, January 2005 (© 2005)
DOI: 10.1007/s10765-005-2359-x

Thermophysical Property Measurements on Mold Materials: Thermal Expansion and Density[1]

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In order to optimize casting processes, computational models of solidification have proven to be very valuable to foundrymen. It is experimentally proven that the casting defects are primarily related to mold properties. During the eutectic growth the temperature rises, which is commonly referred to as recalescence. This has a strong effect on the mold walls, and mold wall movement can occur. The huge pressures generated at this time can block voids if mold is rigid. In green sand molds the moisture content will be reduced and mold wall will expand easily. According to previous research results, a distribution of thermophysical properties of the mold in the mold cavity, and the movement (expansion or contraction) of the mold and the metal interface are crucial for formation of many defects. The thermal expansion and bulk density of selected mold materials (olivine sand and zircon sand) and silica sand cores in transient regimes were determined in this study using a computer-controlled dual-pushrod dilatometer.

KEY WORDS: density; dilatometer; mold materials; sand; thermal expansion.

1. INTRODUCTION

The Metalcasting Industry Technology Roadmap identifies the high priority research needs of the metal casting industry. Many of the needs are interrelated and apply to both technical and market barriers to expanded utiliza-

[1]Paper presented at the Fifteenth Symposium on Thermophysical Properties, June 22–27, 2003, Boulder, Colorado, U.S.A.

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tion of metal castings. Research and development needs in the area of material properties are considered by industry to be the highest priority needs in materials technology. The basic research which defines techniques to measure thermophysical properties of mold materials, directly addresses four of the high priority needs mentioned in the Metalcasting Industry Technology Roadmap and the American Foundry Society (AFS) Molding Methods and Materials Division research plans. They are as follows:

- Development and application of new thermophysical property measurement techniques in transient regimes,
- Improvement of the accuracy of the measurements,
- Application of different techniques to cross-check the property data to increase reliability, and
- Development of a database for most commercially available mold materials.

In order to optimize casting processes, computational models of solidification have proven to be very valuable to foundrymen. Current computer models can predict casting feedability, macroporosity formation, and the development of grain structure in some alloys. Mathematical modeling and control of casting process parameters with mold materials require knowledge of the thermophysical properties of chemically bonded and green molding sand. Mass, momentum, and energy transport processes in this important class of materials can be modeled only if the thermophysical parameters of density, thermal expansion, thermal diffusivity, thermal conductivity, specific heat, and emissivity are known precisely. The accuracy and efficacy of computer simulations depend decisively upon accurate thermophysical properties of both the alloys and molding materials over a wide range of temperatures. It is experimentally proven that shrinkage defects are primarily related to mold properties. During the eutectic growth the temperature rises, which is commonly referred to as recalescence. This has a strong effect on the mold walls, and mold wall movement can occur [1]. The huge pressures generated at this time can block voids if mold is rigid. In green sand molds the moisture content will be reduced and mold wall will expand easily. According to previous research results, a distribution of thermophysical properties of the mold in the mold cavity, and the movement (expansion or contraction) of the mold and the metal wall are crucial for formation of many defects.

Thermophysical property data for mold materials used by simulation engineers have increased tremendously in the last decade, as the development of new binders and additives, and new types of mold materials

require reliable data on thermophysical properties. Commercial devices are available from many suppliers to measure sets of thermophysical properties, such as specific heat, transformation temperatures, thermal conductivity and thermal diffusivity, density, thermal expansion, viscosity, etc. Measurement errors frequently arise from one or more of the following sources:

- Almost all mold materials are very sensitive to temperature changes. Therefore, all thermophysical properties must be measured over wide ranges of temperatures.
- The properties of mold materials change with time. It is necessary to conduct the measurements in transient regimes.

Pehlke et al. [2] and Touloukian [3] presented thermophysical property data for a wide variety of mold materials used in foundry processes. To measure the thermal conductivity of sand molds, Kubo et al. [4–6] applied a pouring technique using aluminum, cast iron, and steel. Atterton [7], Seshadri and Ramachandran [8], and Ninomiya and Nozaki [9] presented the results of thermal conductivity measurements on mold materials at elevated temperatures.

Recently, Midea and Shah [10] presented results of thermophysical property measurements of seven generic mold material samples:

- chemically bonded urethane molding sand
- chemically bonded furan core sand
- chemically bonded shell molding sand
- machine molded green sand
- high pressure molded green sand
- chemically bonded urethane core molding sand
- chemically bonded furan mold sand

Thermal data comparisons in their studies showed slight differences in thermal conductivity, specific heat, and density data between the new data and previous generic datasets. Thermometric measurements during the pouring of steel cubes showed that the new data provide more accurate predictions. However, the authors of this paper acknowledge that the new data have not been extensively validated.

In this study the thermal expansion and bulk density of selected mold materials (olivine sand and zircon sand) and silica sand cores in transient regimes were determined using a computer-controlled dual-pushrod dilatometer.

2. MEASUREMENT TECHNIQUES AND PROCEDURES

Although pushrod dilatometers for measuring thermal expansion and contraction are commercially available from many manufacturers, they must be modified for studying mold materials. A computer-controlled dual-pushrod Unitherm^{TM} Dilatometer (Model 1161 V, Anter Corp.) has been used to measure the density and thermal expansion of mold materials with an uncertainty $\pm 1\%$ (Fig. 1). In this dilatometer, one end of a spring-loaded pushrod is attached to the sensor element in a linear variable differential transformer (LVDT) and the other end is placed into contact with the sample material. A similar pushrod was attached to the housing of the LVDT and then placed against a well-characterized reference standard. As the sample and reference material expand, the LVDT output is a voltage that is proportional to the increase in length of the sample. In this study a graphite crucible, 10 mm inner diameter and 25 mm long, was filled with the test mold material. A cylindrical pushrod of the same diameter and 100 mm long was positioned inside the crucible in direct contact with the top of the sample. The assembly of crucible-sample-pushrod was positioned inside the furnace. The samples were heated to 1200°C at a rate of $20°C \cdot min^{-1}$ in the inert gas (nitrogen) environment.

3. RESULTS AND DISCUSSION

In the modern metalcasting industry the sand reclamation is one of the important parts of environmental and economical benefits. Therefore,

Fig. 1. Computer-controlled dual-pushrod Unitherm^{TM} Dilatometer (Model 1161V, Anter Corp.) to measure the density and the thermal expansion of mold materials.

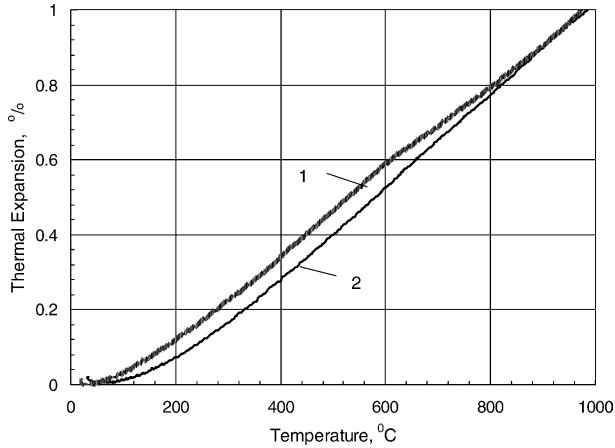

Fig. 2. Variation of the thermal expansion coefficient of olivine sands (1-first used and 2-reclaimed) with temperature.

it is of practical importance to measure thermophysical properties of fresh and reclaimed mold materials. Figure 2 shows the variation of the thermal expansion of fresh and reclaimed olivine sands with temperature. As seen from this figure, the thermal expansion of fresh olivine sand is higher than that for reclaimed olivine sand. Figure 3 demonstrates the difference in thermal expansion for fresh and reclaimed olivine sands. As seen from this figure, the maximum difference (~6.5%) in thermal expansions occurs between 400 and 600°C. At temperatures above 600°C the test sand loses its "freshness," and its thermal conductivity does not differ from that for reclaimed sand. From thermal expansion data, along with a knowledge of the density of the sand specimens at room temperature, one can easily estimate the bulk density of the sample. Figure 4 shows the variation of the density of the fresh and reclaimed olivine sands with temperature. As expected, the density of the fresh sand is lower than that for reclaimed sand.

Figure 5 shows the variation of the thermal expansion of zircon sand with temperature. As seen from this figure, the thermal expansion of zircon sand varies with temperature in a quite complex manner. With a temperature increase from room temperature up to 100°C, the zircon sand contracts almost 0.04%. One would assume that the contraction is related to the evaporation of any moisture and burning of certain organic inclusions in the sand. A further increase in the temperature results in an increase of the thermal expansion for zircon sand. However, fragment decreases in thermal expansion were observed at 500 and 1000°C. Again,

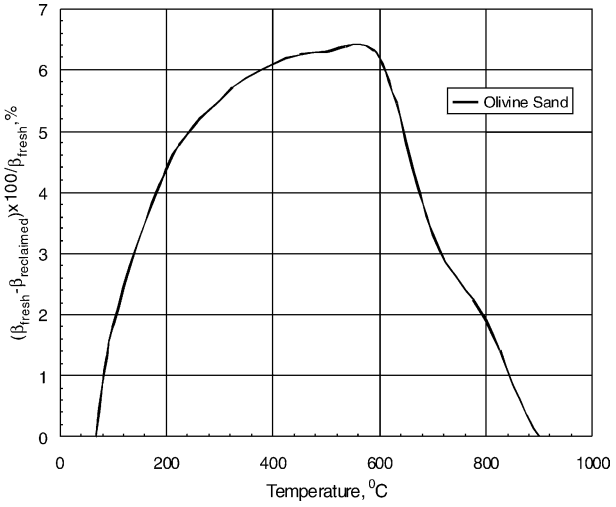

Fig. 3. Comparison of the thermal expansion of fresh and reclaimed olivine sand.

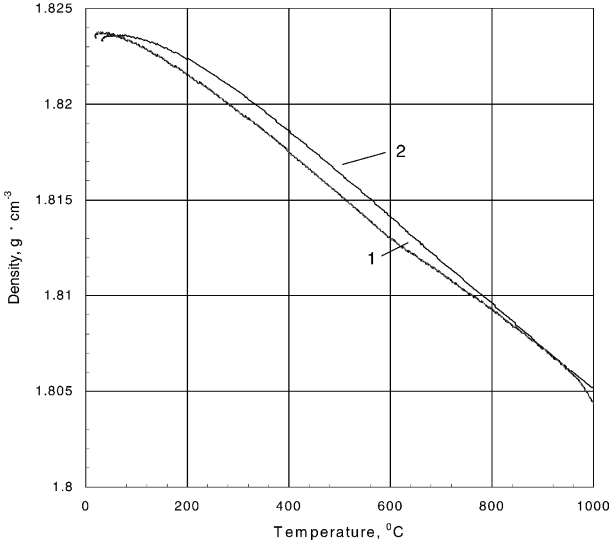

Fig. 4. Variation of the density of olivine sands (1-first used and 2-reclaimed) with temperature.

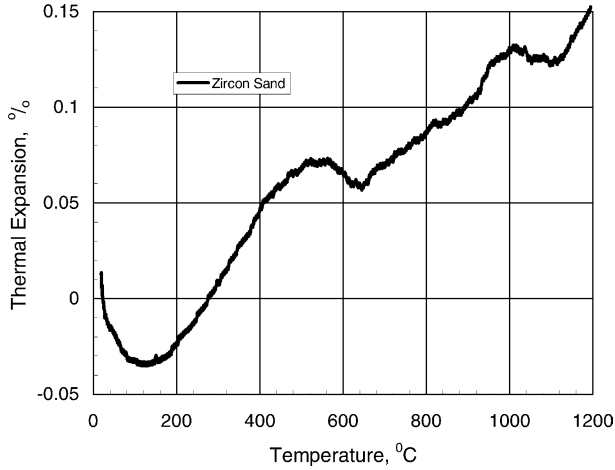

Fig. 5. Variation of the thermal expansion coefficient of zircon sand with temperature.

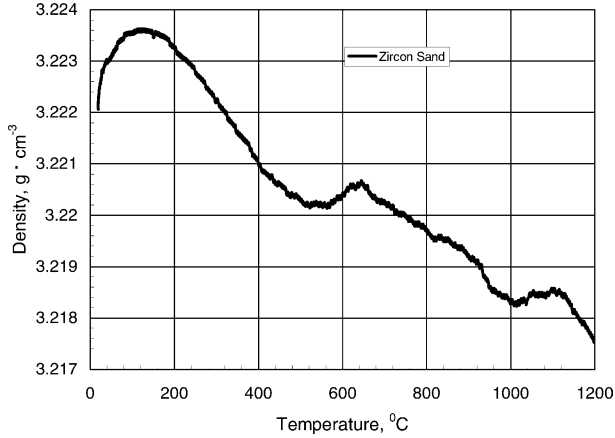

Fig. 6. Variation of the density of zircon sand with temperature.

one would assume that certain compounds were burned out at these temperatures. Thermal expansion data allowed estimates of the variation of the density of the zircon sand. Figure 6 demonstrates the variation of the bulk density of the zircon sand with temperature.

In this study we also produced cylindrical core specimens of 2.5 cm length and 1 cm diameter. The silica sand was bonded with Isocure resin

binder using commercial Laempe Core Shooter Model L1. Two types of specimen were tested in this study:

- Specimen #1: 1.3% binders (50/50 of part 1 to part 2 ratio), and
- Specimen #2: 1.5% binders (50/50 of part 1 to part 2 ratio).

The results of thermal expansion/contraction analyses are presented in Fig. 7. As seen from these data, at temperatures up to 300°C both sand cores do not show any significant changes in volume. However, up to 0.1% expansion for specimen #2, and up to 0.1% contraction for specimen #1 can be observed at temperatures up to 300°C. At temperatures above 300°C, a dramatic contraction for both sand core samples was observed. Specimens #1 and #2 contract 2.3 and 1.75%, respectively. At a temperature of 360°C, the contraction process ends and the cores begin expanding. The expansion process stops at a temperature of 580°C, and no further changes in density were observed with increasing temperature up to 800°C. The observed phenomena have the following explanation. At temperatures up to 300°C, due to combined effects of expansion and contraction of sand and resin binder, there are no significant changes in the specimen volume. At temperatures of 300°C and above, the resin binders start melting and then burning off. Therefore, the core specimens contract. When the resin binders are completely burned off ($T = 360$°C), the contraction process stops, and sand grains, free of resin binders, start expanding. This process continues up to 560°C, and then the expansion process

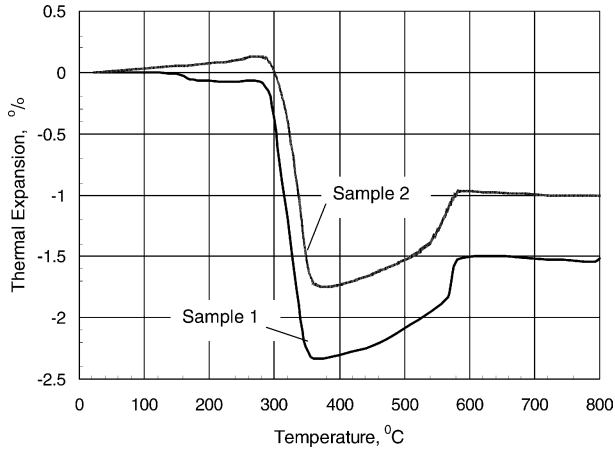

Fig. 7. Variation of the thermal expansion/contraction of sand core specimens with temperature.

stops. Visual observations of the sand cores after the tests confirmed this explanation. It is interesting to note, that after the tests were completed specimens #1 and #2 lost masses of ~1.3 and 1.5%, respectively, which is the mass of resin binders in the sand core.

4. CONCLUSION

The thermal expansion and bulk density of olivine and zircon sands, and silica sand cores are measured as a function of temperature using a computer-controlled dual-pushrod dilatometer. The thermal expansion of fresh olivine sand was up to 6% higher than that for reclaimed olivine sand. The thermal expansion and bulk density of the zircon sand vary with temperature in a quite complex manner due to inclusions. A more complex relationship between thermal expansion/contraction and temperature was obtained for silica sand cores. The amount of the mass loss during the tests corresponded to the amount of the binders in the core.

ACKNOWLEDGMENT

The authors gratefully acknowledge financial support received from NASA's Space Product Development at Marshall Space Flight Center under Cooperative Agreement No. NCC8-240.

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