Industry and Academia Collaboration for a Thermal Distortion Tester for Sand-Binder Systems

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Abstract

The goal of this industry and academia collaboration has been the design and development of a prototype Thermal Distortion Tester (TDT) to be used in the foundry industry. This apparatus measures thermal distortion in chemically bonded foundry sands; thus providing the foundry engineer with proper information to reduce dimensional variations in cast parts as a result of thermal distortion in molds and cores. A concept prototype has already been developed and used for initial testing. The thermal properties for various chemically bond sands have been investigated. The sand-binder mixtures selected for this study demonstrate the capability of the developed tester to deal with diverse combinations. The distinctive results obtained confirm that the tester is a valuable tool that can aid the foundry engineer in predicting the behavior of core and mold material in thermo-mechanical applications, thus helping in dimensional control. It is our belief that this collaboration has been a successful one based on the interest in the prototype TDT shown by foundry practitioners and binder manufacturers.

Introduction

Because of the increasing demands for performance and productivity, interaction between academia and industry is of particular importance nowadays. This interaction should help both sides: academia people have the opportunity to apply their knowledge and experience in a *real* situation, and industry people get the benefit of having additional knowledge and technology sources available to them. This project illustrates one of such interactions. It started when some academia and industry people recognized a need for the foundry industry and it was decided to work together on such problem. Manufacturing, Graphics, and Design faculty and students at the Department of Industrial and Manufacturing Engineering (IME) at Western Michigan University (WMU), together with technical personnel from the Instruments Division at Georg Fischer-DISA (GF-DISA) have been working on the development of a TDT for chemically bonded sands.

Sand molding is, by far, the most common casting process used in the United States. According to the American Foundrymen's Society (AFS), close to 90% of the annual castings produced nationwide are sand castings[(1)]. Such popularity, due in part to the high level of applicability that sand casting offers, has resulted in many technical developments towards a more efficient process. For resin binder processes, which can be classified as: no-bake systems, heat-cured systems and cold box systems, technological advances on the chemicals used for the binders and the catalysts have resulted in very efficient and environmentally friendly processes. At the same time, the metalcasting industry has realized that in order to fulfill customers needs in the future there is one major challenge that must be addressed: near-net shape castings[(4)]. The goal is to produce cores and molds of consistent dimensional accuracy, and hence a casting satisfying the increasingly tighter tolerances of the customer. The developers and users of chemical binders in hot or cold corebox or on patterns for molds, all have this issue in mind.

Today, both hot and cold processes achieve this objective successfully for core and mold production when room temperature dimensions are concerned. But the dimensional accuracy, strength, and hardness of cores and molds at room temperature bear little or no relationship to behavior during casting. The thermal expansion, distortion, and breakdown which the core and mold undergoes during casting is directly related to the type of sand and binder in use. Apart from the binder, there are many other factors that can affect dimensional stability. Gating system design, cope height, metal temperature, pouring rate, handling properties, and type of molding media can all have an impact on core and mold dimensional stability.

Bonded sands undergo considerable dimensional changes when subjected to heat and mechanical stresses from molten metal. Sand must be able to withstand the thermal and mechanical parameters of the molding and casting process. Additionally, distortion characteristics of the various chemical binders differ considerably. If the sand-binder system is not stable, there is a tendency for the mold wall to dilate when molten metal is poured into a sand mold. The mold cavity dilates due to the combination of thermal expansion and liquid-metal pressure and during solidification, a gap between the casting surface and the mold wall may form. The result could be oversized castings[7]. To produce castings of consistent quality, it is therefore important to know the thermal properties of sand-binder systems used in manufacturing cores and molds. The foundrymen must make decisions that allow for the least amount of dimensional variations during molding, handling and casting. A non-quantitative approach is often used for deciding which process should be used for various cores and molds. A good understanding of the inherent properties of each available binder system is necessary to insure the selection of the most appropriate core and moldmaking process.

This industry-academia collaboration focuses on the development of a thermal distortion test that measures distortion in sand-binder systems at a specified temperature. A prototype apparatus has been developed and is being used to measure the variations due to thermo-mechanical effects on the different binder systems. With the exception of sand and binder types, all other variables are kept constant. Shell and No-bake sand-binder systems were tested. It can be said that, based on the results obtained, the thermal distortion testing methodology being utilized is a reliable tool that can help in sandcasting processes.

The Collaboration

The idea for this project was originated after several conversations took place between WMU faculty members and industry people at various professional gatherings/meetings. During those informal conversations it was recognized that a need existed in the foundry industry for more objective options to evaluate the behavior of chemically bonded sands. Once the importance of such need was evaluated in terms of technical and service issues, WMU and GF-DISA held further conversations that resulted in an initial agreement for a collaboration in the design and development of a prototype thermal distortion tester. This non-legal agreement contemplated the contribution of technical expertise and shop time by both parties for the construction of a prototype. In general terms, it was decided that conceptual engineering would be carried out by both sides, with all additional engineering being performed at WMU; manufacturing being performed at GF-DISA and WMU; assembly at WMU, and testing at both sites. College (WMU) and management (GF-DISA) approval was required in order to work this agreement without any specific budget but with the understanding that both parties will provide as much in-kind contribution as possible and necessary, with each party covering its own expenses.

The main elements that made this collaboration possible were the expertise from and the benefits for both parties. Faculty at WMU has the expertise in terms of design, foundry processes, prototyping and testing, and GF-DISA has the expertise in terms of foundry instrumentation, commercial production, precise manufacturing and vendor relationship. Regarding benefits, faculty and students (i.e., a Senior Project group) at WMU had the opportunity to participate in a *real world* project, which included all phases of product development: conceptual design, basic and detailed engineering, manufacturing and testing. All of these activities including the practicalities of project management and team work experiences. For GF-DISA, the benefits received include the accessibility to additional expertise and help in the foundry and design fields, and the access to state-of-the-art facilities and equipment for engineering design purposes.

The Tester

Background. Government regulations and competition have forced engineers to design castings that are lightweight and still able to perform effectively against their competitors' products. Lightweight often means that the casting wall thickness must be reduced. This increases the need for consistent casting dimensional integrity. To adhere to these standards, it is important to be able to predict the general characteristics of each core and moldmaking process[(5)]. Similarly, customers are asking foundries to produce to near-net shape, which puts even more emphasis on reducing core and mold distortion during the casting process[(2)], therefore means for predicting thermal distortion are needed.

The British Cast Iron Research Association (BCIRA) in 1966 developed a Hot Distortion Tester for quality control in production of chemically bonded sands[(8)]. But there are various inherent problems with their approach: the heat source for this tester is a gas burner with no direct control over heat input, the open flame interacting with the chemically bonded sand is not the best simulation of conditions occurring in actual foundry practice. Additionally, the test piece is loaded as a cantilever beam, where small deviations at the cantilever support results in significant distortion at the opposite end. Since no other apparatus or test exists for thermal distortion testing of sand-binder systems, the purpose of this collaboration study was to design and develop a concept prototype tester for sand-binder systems, and to define a general testing procedure for chemically bonded sands.

Apparatus. The principle selected for the operation of the prototype tester was a pivoted arm. The reason for this selection is that the pivoted arm allows for the application of the mechanical and thermal loads on each side of the specimen at the same time. As can be seen in Figure 1, the swinging arm, initially balanced to stay horizontal, is used to apply the load on top of the specimen and the thermal load underneath the specimen. The test piece is mounted on a specimen holder, which also serves as reference point for the displacement measures. Adjusting the amperage feed to the heating element (cylinder on the left) controls heat flow; displacement

Figure 1. Thermal Distortion Tester (TDT)

Figure 2. Specimens. Pre/Post.

is measured based on a fixed point in the frame of the apparatus. A data acquisition system collects temperature (thermocouple) and displacement (LVDT) information during the test.

Test Methodology. In this project the methodology proposed and used for testing is based on the goal of predicting the performance of a variety of sands and binders with the proposed TDT. Because of the particular concerns expressed by AFS-related experts in the field of sands-binder systems, shell and no-bake systems were tested. Two different types of shell sands, one for molds and one for cores, and two different types of sands, silica and chromite, with one no-bake binders, were tested. Each experiment consists of the following major steps:

1. Fabrication of specimens. Blowing mixture into jig and curing.
2. Scratch hardness testing. AFS Standard 318-87-S[1]
3. Disc Transverse Strength Testing. Tinius Olsen apparatus.
4. Thermal Distortion Testing. Prototype TDT.
5. Data Analysis. Commercial spreadsheet software.

Evaluation and Results

A prototype TDT was developed and evaluated. Several issues regarding thermal distortion and practical information for industry have been addressed with this prototype tester. In terms of the specimen used, the developed TDT uses the disc transverse strength specimen (1.97 in diameter, 0.31 in thickness, Figure 2) as the test piece. Disc transverse strength is a valid alternative test for chemically bonded sands. It offers better repeatability due to a far more consistent plane of failure[6]; and it simulates (similar type of mechanical stress) and correlates (common failure types) better with critical thin section failures found in actual cores and molds in the foundries. The developed TDT can be used at specific temperature settings; for example 1400°F for aluminum, 2200°F for brass, and 2500°F for cast iron. In addition, the test piece is subjected to direct contact with the heat source much like molten metal. The compressive stress applied to the specimen as it experiences specified heat is similar to the type of mechanical and thermal stresses that causes core and mold failures in actual foundry practices. A qualitative evaluation for smoke evolution from the test piece can be made with the thermal distortion tester. This is possible by the absence of combustion at the heat source used in conjunction with the test piece.
The rigid sand-binder test piece undergoes a characteristic structural change when heated in the TDT. This change is reflected in the shape of the Distortion *vs.* Time curves for each of the mixtures tested. This thermal distortion curves are characteristic of the behavior of the test piece

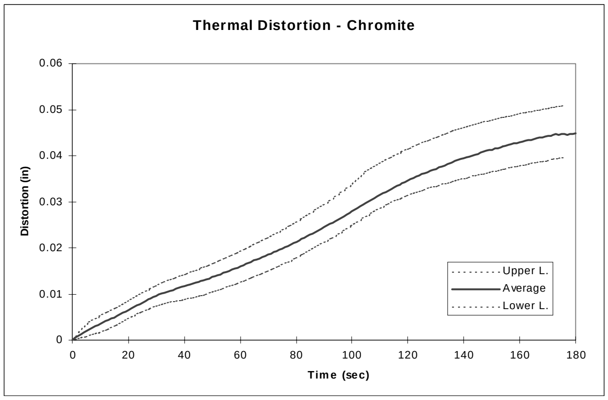

Figure 3. Results for No-Bake Mix.

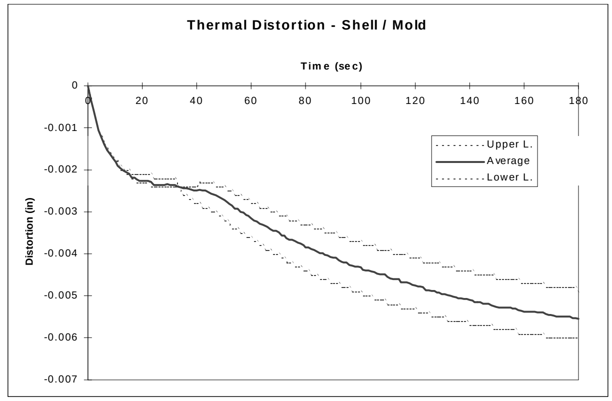

Figure 4. Results for Shell Mix.

during heating and loading. Distinctive curves were obtained for the no-bake mixtures (Figure 3) and the shell systems (Figure 4); with no-bake showing basically a continuous high-temperature structural distortion with time, and shell showing a combination of thermal expansion and high-temperature structural distortion. Final distortion is significantly higher for the no-bakes.

Table 1 shows a partial comparison of results for tested properties on the disc shaped specimens. Disc-shaped specimens used in all tests were consistent from a mass measure. Scratch hardness and transverse strength results identified proper cure in both systems. Regarding correlation between standard tests and thermal distortion, no-bake systems showed lower transverse strength than shell sands, but higher maximum distortion; similarly, no-bake mixtures showed slightly higher scratch hardness with higher distortion. These results basically confirm the need for thermal distortion testing of sand-binder systems.

With thermal distortion testing, a more reliable approach to sand-binder control is achieved by producing consistent, verifiable results on specimens exposed to actual core and mold production and storage conditions. The proposed TDT can be used for process control activities such as: a) material development and control, b) dimensional concerns, and c) environmental concerns.

Acknowledgements
We would like to acknowledge the following people for their participation and contributions to this project: Lonnie Beckwith, Rodney Burkhardt, Doug Busch, William Sager, and Glen Hall.

Table 1. Summary of Results

Process Type	**Sand Type**		**Scratch Hardness** (#)	**Transverse Test** (lb)	**Initial Weight** (g)	**Weight Loss** (%)	**Maximum Distortion** (in)
No-Bake	**Silica**	Ave	90.25	41.433	23.994	2.376	0.0378
		SD	2.754	8.302	0.223	0.437	0.0068
	Chromite	Ave	97.125	35.167	42.976	1.428	0.0433
		SD	1.436	10.528	0.501	0.149	0.0075
Shell	**Mold**	Ave	92	66.64	22.627	0.777	0.00222
		SD	2.574	11.509	0.515	0.268	0.0013
	Core	Ave	84.33	80.583	23.96	0.676	0.00554
		SD	2.96	6.855	0.281	0.246	0.00044

Conclusions

The collaboration between WMU and GF-DISA was a success. A prototype Thermal Distortion Tester for sand-binder systems has been designed, built and tested. The TDT and the test procedure basically provide the foundry engineer with a process control tool that more closely emulates the thermo-mechanical loads experienced by a sand-binder system during the metal casting process. As this prototype equipment is refined for thermal distortion testing, new applications for measuring loss of sand and binder due to thermal decomposition, and the time it takes for smoke formation with a binder system will be developed. The concept and prototype has received favorable opinions from the foundry industry, production and laboratory personnel. Further collaborations in this field, regarding this tester and other possible process control tools, are being contemplated.

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