AN APPARATUS FOR INVESTIGATING THERMAL DISTORTION IN BONDED SANDS

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The promises of many new alternatives for sand as a medium for the production of cast metal parts have garnered attention of research and press. Yet, close to 90% of annual cast metal production is still done with sand. Its versatility and ease of use foster rapid innovation in an industry where the ability to change quickly can mean survival. This is especially true for chemically bonded sand. Sand has many pluses, but it is far from perfect. Most of the problems with sand castings are due to variations. These variations are mainly in the characteristics of the medium and the materials being utilized, as well as in the process itself. But even with those variations, the popularity of sand-binder systems keeps increasing, and the search for near-net shaped castings keeps going.

In order to accomplish near-net shapes it is necessary to control the thermal distortion suffered by molds and cores, an issue that has not been studied that much in the field. The utilization of the developed device for investigating thermal distortion in chemically bonded sands is presented. The device is capable of placing variable loads on sand-binder samples at metal pouring temperatures. The testing is done without combustible gases. The device, developed at Western Michigan University, has undergone several design modifications that improve ease of use and safety. The basic operation of the device is discussed, and sample distortion curves from performed tests are presented and discussed. The results obtained so far indicate that this apparatus is a useful tool to generate comparative curves that can be utilized during initial selection of sand-binder materials.

Introduction

The use of chemical binders in hot or cold core-box or on patterns for molds, all have one main common goal: near-net shape castings. The goal is to produce cores and molds of consistent dimensional accuracy, and hence a casting satisfying the increasingly tighter tolerances of the customer. This is true in the automotive industry where complex thin wall casting must mate in close tolerance with various other manufactured components and sub-assemblies. Today, both hot and cold processes achieve this goal successfully for core and mold production when

dimension at room temperature are considered. But, bonded sands undergo considerable dimensional changes when subjected to heat and mechanical stresses from molten metal. The thermal distortion and breakdown that the core and mold undergoes during casting are directly related to the type of sand and binder in use. 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.[1] The dimensional accuracy, strength, and hardness of cores and molds at room temperature bear little or no relationship to performance during casting. To produce castings of consistent quality[2], it is therefore important to know the thermal properties of sand/binder systems used in the production of cores and molds.

The purpose of this project was to develop a process control tool for measuring thermal distortion in chemically bonded sand systems. The objectives of this study were: 1) to develop a thermal distortion tester (TDT) for use with the disc transverse specimen (DTS), and 2) to define the protocol to follow in order to acquire useful information relating to thermal distortion properties of chemically bonded sands.

Background

In 1966, the British Cast Iron Research Association (BCIRA) developed a Hot Distortion Tester for Quality Control in Production of Chemically Bonded Sands.[3] 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. In addition, the test piece is 2.54 cm x 0.64 cm x 10.80 cm and is loaded in cantilever. Hence, small deviations at the cantilever support results in significant distortion at the opposite end. In the metal casting process, very rarely do cores and molds experience cantilever loading.

The DTS is an alternate to tensile test specimens for chemically bonded sands. It has several advantages over the old "dog bone" specimens, and is needed by today's metal casting industry. Foundries can no longer tolerate the extreme variability in tensile testing, caused primarily by an inconsistent plane of failure, resulting in shoulder breaks in the midsection of the tensile specimen. Tests with DTS offer better repeatability due to a far more consistent plane of failure.[4] The DTS simulates and correlates better with critical thin section-failures, since it uses a thin specimen (i.e., 5 cm diameter x 0.80 cm thickness) and the type of stress induced is very similar to the type of mechanical stress that causes core and mold failures in actual foundry practice. The disc may easily be incorporated into production tooling so that discs can be made with production cores and molds.

The TDT developed at WMU uses the disc specimen (DTS) as the test piece. Unlike the BCIRA Hot Distortion Test, the thermal distortion tests can be used to simulate a specific temperature setting; for example 760°C for aluminum, 1210°C for brass, and 1375°C for cast iron. Additionally, the test piece is subjected to direct contact with the heat source that simulates molten metal. Similarly, the stresses induced in the specimen during the test are similar to the type of mechanical and thermal stresses that causes core and mold failures in actual foundry practice. Another aspect of the developed TDT is that because a clean heat source is used during the testing procedure, a qualitative evaluation for smoke generation from the test piece can be

made. As well, based on the initial mass of a specimen and the mass after thermal distortion testing, a percent degradation loss of specimen can be determined.

Methodology

The defined testing methodology consists of four major steps, which are described in the next paragraphs. It is important to note that all specimens preparation and testing needs to be performed in a controlled laboratory environment. Temperature was controlled at 23.9±1.1°C, and relative humidity was controlled at 50±3%. The four steps are:

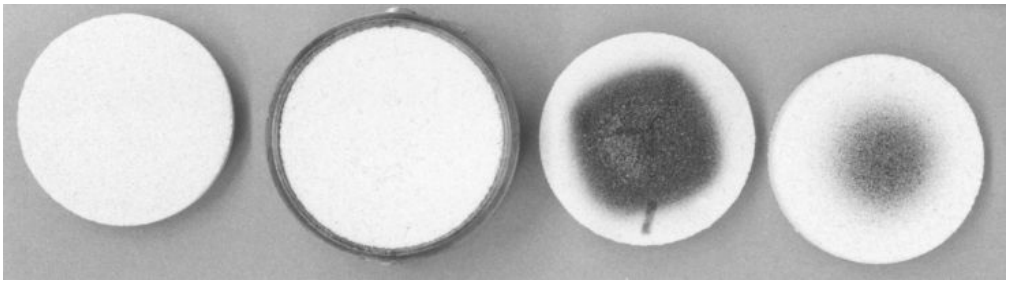
- Preparation of Disc Shaped Specimens
- Scratch Hardness Testing
- Thermal Distortion Testing
- Testing Methodology

1. Preparation of Disc Shaped Specimens

The DTS are used because is this test because there are well accepted in the industry, and its preparation is a standard process. The materials selected for the runs presented here are: a) sand: silica sand (Illinois AFS/gfn 50, rounded and neutral pH), and b) binders: Number I: organic, 50% phenolic and 50% polyisocyanate, with a 1% of catalyst; Number II: inorganic, silicate, with a 10% of catalyst. The binder to sand ratio was used according to manufacturer specification, i.e., based on weight of sand, a 2% binder for Number I and 3.5% binder for Number II. The sand, binder and catalyst are mixed in a laboratory sand mixer for two minutes. Then the mix is placed in a fixture that has, in our case, 4 spaces of 5.0 cm diameter by 0.80 cm thickness. The mixture is blown at 552 KPa air pressure from a core-shooter into the disc-shaped specimen jig and fixture. The jig and fixture has removable plates so that, after curing, the test piece may be easily removed without damaging the specimens. The specimens (Figure 1a) are then placed on a flat surface to complete the hardening process. The strip time was six minutes.

2. Scratch Hardness Testing

The scratch hardness test[5] is used as an indicator of specimen consistency. The specimens are tested according to standard AFS Scratch Hardness Test 318-87-S, which is performed with a commercial Scratch Hardness Tester. Batches of 15 specimens are used for statistical validity.



(a) (b) (c) (d)

Figure 1 - Specimens at various stages in testing

Figure 2 - Thermal Distortion Tester

3. Thermal Distortion Testing

The actual distortion testing is performed in the developed TDT (Figure 2). The TDT is based on an induction furnace that has been modified to applied load in addition to heat. To operate the TDT, electrical power is switched on and the amperage adjusted to simulate a specific molten metal temperature (molten aluminum was simulated in this study, 760°C). The computer and data acquisition system was switched on for on-line monitoring and plotting graphs for temperature versus time and distortion versus time. The specimen is inserted into the holder designed for the disc shaped specimen (Figure 1b), and the holder is lowered until a direct symmetrical contact was made with the 2.0-cm diameter heat source. The linear displacement transducer that measures distortion is simultaneously engaged. The experiment is performed with a predetermined load of 5 N to simulate a force pressing against the core or mold. The load is applied to the circumference of the specimen. This predetermined load can be adjusted to simulate a specified force of molten metal acting on the mold or core. The data acquisition system automatically logs and plots the distortion versus time/temperature curve. The length of the test is set for three minutes. Figure 1c and 1d illustrate the final condition of the specimens after testing. Figure 1c correspond to binder I and figure 1d to Binder II, and the different level of carbonization can be observed. This test is as well performed on batches of 15 specimens.

4. Transverse Test

The transverse shear test is performed on the specimens used for the thermal distortion test. The reason for the test is to have an indication on the level of friability of the specimens after being subjected to thermal and mechanical loads. The test is performed on a Tinius Olsen machine equipped with disc-shaped specimen holder and a blade. For the test, the specimen is fitted into a specimen holder on the testing machine and it is supported on its ends. It is then subjected to a standard transverse force applied with a 3.0-mm thick blade across its diameter. Loading is performed at a constant rate of 0.25 cm/min. A load-cell electronically senses and responds to specimen failure. The maximum load to failure is measured and digitally displayed.

Results

A prototype TDT (Figure 2) has been developed for use with the disc specimen (DTS) as test piece. The rigid sand/binder test piece undergoes characteristic structural change when heated and loaded in the TDT. Such characteristics are reflected in the shape of a Thermal Distortion Curves (TDC) obtained for different sand/binder combinations, as seen in Figures 3 and 4.

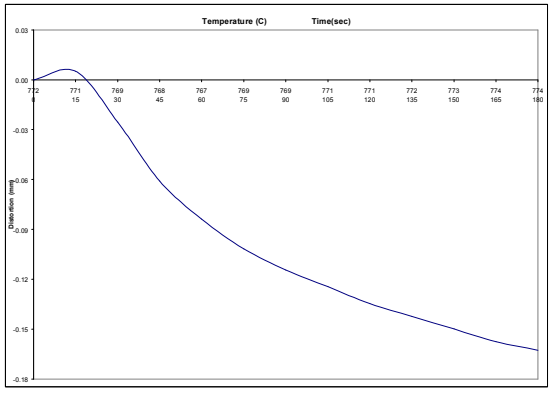


Figure 3 - Typical TDC with binder I

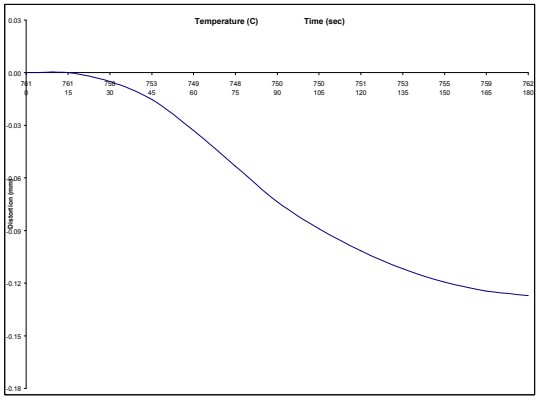


Figure 4 - Typical TDC with binder II

A TDC is a graph of distortion versus time/temperature, for the duration of the test. The distortion curve results from the thermal expansion and thermal degradation of the sand/binder test piece. Table 1 shows a comparison of results for tested properties on the DTS. Disc-shaped specimens used in all tests were consistent in terms of mass measure. Additionally, scratch hardness results identified proper cure in both binder systems. However, the transverse strength was significantly higher in binder I. On the other hand, there was significantly less thermal distortion for test pieces made with binder II; this would be expected since silicate systems are known for their thermal strength (poor shakeout) at aluminum pouring temperatures.

Table 1 - Results of Thermal Distortion, Scratch Hardness, and Transverse Strength

Binder Type	**Thermal Distortion**				**Scratch Hardness**	**Transverse Strength**
	Original Mass (g)	***Final Mass (g)***	***% Thermal Degradation***	***Distortion (mm)***	***Number***	***Force (N)***
X_I (ave)	26.5	25.7	2.8	0.3556	86	182
σ_I (S.D.)	0.29	0.42	0.47	0.0762	2.4	7.1
X_{II} (ave)	24.7	24.6	0.54	0.1016	86	107
σ_{II} (S.D.)	0.25	0.11	0.23	0.0254	3.2	17.8

Given the fact that binder I showed greater transverse strength and binder II showed less thermal distortion, no relationship between mechanical properties (i.e., hardness and transverse strength) and thermal distortion was identified for each of the tested chemical binder systems. Several sand-binder combinations have been tested, with similar results. Additional observations are being collected (Table 2) in order to eventually be able to define correlations based on the sand and binder being utilized.

Table 2 - Comparison of Observations During Thermal Distortion Testing

	Binder I	**Binder II**
Loss of sand and binder due to thermal decomposition	Significant (Table 1)	Negligible (Table 1)
Smoke formation	Present 50 -55 sec after starting a test	No occurrence
Discoloration of specimen	Charred (Figure. 1c)	Minimal (Figure. 1d)

Conclusions

The developed TDT provides the foundry engineer with a process control tool that more closely represents the thermo-mechanical experiences of a sand/binder system during the metal casting process. The device has proven to be adequate to distinguish between thermal behaviors of various sand/binder combinations. As this prototype equipment is refined for thermal distortion testing, new applications for measuring loss of sand and binder, due to thermal degradation, and the time it takes for smoke formation with a binder system will be developed.

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