

Non-standard tests for process control in chemically bonded sands

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Abstract: Chemically bonded sand cores and molds are more commonly referred to as precision sand systems in the high production automotive powertrain sector. Their behavior in contact with molten metal can lead to casting defects. Consequently, the interaction is of great interest and an important part of metal casting technology. The American Foundry Society (AFS) sand testing is based on physical, mechanical, thermal and chemical properties of the sand system. Foundry engineers have long known that certain AFS sand tests provide limited information regarding control of molding and casting quality. The inadequacy is due to the fact that sand casting processes are inherently thermo-mechanical, thermo-chemical and thermo-physical.

Non-standard foundry sand testing has proven useful for laboratory measurement of these characteristics in foundry sand using a disc-shaped specimen. Similarly, the equivalent disc-shaped specimens are used for casting trials. In order to accomplish near-net-shape casting with minimal defects, it is necessary to understand both the properties of the sand system, as well as the interface of molten metal when different binders, additives and/or refractory coatings are used. The methodology for the following non-standard chemically bonded sand tests is described: (1) disc transverse; (2) impact; (3) modified permeability; (4) abrasion; (5) thermal distortion; (6) quick loss on ignition. The data related to the non-standard sand tests were analyzed and interpreted. The test results indicate that there is relatively lower test-to-test variability with the disc-shaped specimens. The non-standard tests were able to discriminate between the chemically bonded polyurethane cold box sand specimens. Further studies should be conducted on various other sand and binder systems as well as on different specimen thicknesses.

Key words: chemically bonded sand; permeability test; thermal distortion test; loss on ignition

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The most popular medium for the production of cast powertrain metal parts is sand. Sand has many pluses, but it is far from perfect. Problems with chemically bonded sand systems arise from variation in materials and processes. This can come from many sources such as grain size, grain shape, chemical composition, binder level, additives, work-time, strip time, pouring temperature, metalostatic pressure, etc.^[1]. Thus, chemically bonded sand has many potential sources of variation; but it is still subject to the pressures of delivering near-net shaped

castings. Understanding those variations is a key issue for achieving good process control, and there have been several studies toward that end.

Sand's versatility and ease of use foster rapid innovation in an industry where the ability to change quickly can mean survival. This is especially true with the development of chemically bonded sand systems. Unfortunately, the binder system is also a significant source of variation. The concentration of binder in the sand, and the mix of the binder constituents can all have significant effects on the final castings. Additionally, new binders are constantly being developed in response to various environmental and product quality concerns, thus creating new potential sources of variation.

Chemically bonded sands used with cores and molds are conventionally processed by techniques such as hot-box, no-bake, and cold box^[1]. When sand composites (mold and core media) come in contact with elevated temperature, the heat transferred causes thermo-mechanical movement and thermo-chemical reactions that result in dimensional changes at the mold-

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metal interface. At any given temperature these dimensional changes or thermal distortions are attributable to simultaneous changes in both the sand and the binder. Depending on the type of binder used and the temperature at any point in the sand plane, thermally induced reactions occur simultaneously along with sand expansion leading to significant distortions in the composite shape^[2].

A disc-shaped specimen has been used as a supplementary mechanical test specimen for chemically bonded sands in the foundry industry. With the support of the American Foundry Society (AFS), Western Michigan University (WMU) has developed non-standard thermo-mechanical and physical tests for chemically bonded sands employing the same simple geometry for a specimen.

1 Aim

To ascertain non-standard foundry sand testing using chemically bonded disc-shaped specimens for:

- (1) Disc transverse
- (2) Impact
- (3) Modified permeability
- (4) Abrasion
- (5) Thermal distortion
- (6) Quick loss on ignition

2 Methodology

The methodology consisted of two major steps: preparation of chemically bonded disc-shaped specimens and testing of disc-shaped specimens. To ensure that the study was executed methodically, an experimental design of two binder levels at elevated temperature with 15 specimens per cell was employed. (Note: All specimens were prepared and tested in laboratory conditions. Ambient conditions were controlled: temperature at 20 ± 1 °C and relative humidity at $50\% \pm 2\%$).

2.1 Preparation of PUCB specimens

Polyurethane cold box (PUCB) specimens were prepared using washed and dried round grain silica sand (Table 1).

Table 1: Properties of PUCB sand

Source	AFS /GFN	Shape	PUCB resin (%)	Roundness/sphericity (Krumbein)	pH	Acid demand (pH 7)
Illinois	59-65	Round	0.9 or 1.4	0.8/0.8	7.1	0.8

The PUCB disc-specimens (50 mm dia., 8 mm thickness) were prepared by blowing with a laboratory core blower into a three-cavity disc core box (Fig. 1). Each cavity had its own gate opening and a vent opposite the gate.

Materials: Silica sand (Table 1), PUCB binder system Part 1 and Part 2 (mixture ratio of 55 Part 1: 45 Part 2)

Equipment: DeLonghi mixer, core box, core blower.

Procedure:

- (1) Add weighed sample of sand to DeLonghi mixer;

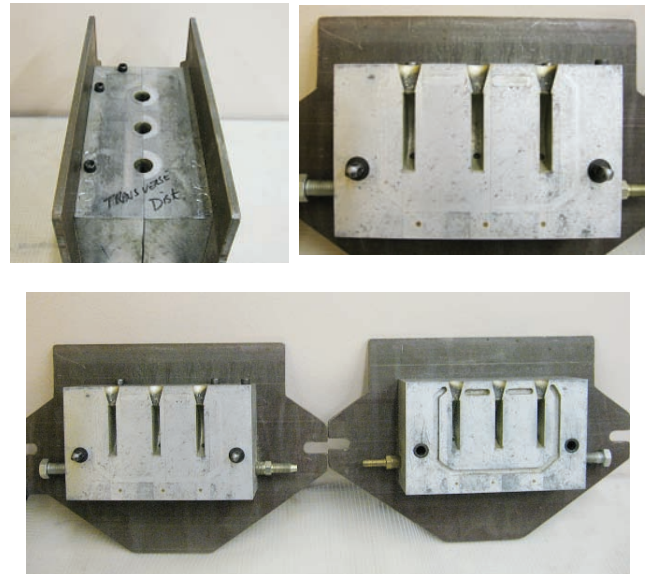


Fig. 1: Three-cavity disc core box

- (2) Make two pockets in the sand;
- (3) Add Part 1 component into one pocket and Part II to the other pocket;
- (4) Mix for 1 min;
- (5) “Flip” mixture and mix for 1 additional minute;
- (6) Using laboratory core blower set at 0.379 MPa (55 psi) for 0.5 s blow the mixed sand into the three cavities of the core box (Fig. 1);

(7) Cure by gassing with TEA using a Luber gas generator. Gassing parameters: 1 s gassing with TEA, followed by an air purge for 6 s [gas pressure was 0.172 MPa (25 psi) and air purge pressure was 0.103 MPa (15 psi)].

2.2 Specimen weight

The disc-shaped specimens were weighed prior to conducting any tests using a four place digital balance and the weights were recorded. The purpose of this measurement check is to identify specimen-to-specimen variability.

2.3 Disc transverse strength (DTS) test

Disc transverse strength tests (DTS) were used to measure the strength of the sand specimens prior to the thermal distortion test (TDT), and after TDT. Strengths before TDT relate to handling of the core/mold material after core/mold production, prior to pouring. The strengths after TDT relate to shakeout/collapsibility characteristics.

Equipment: A sand strength machine (Dietert Model 490-A) equipped with a disc transverse accessory (Fig. 2).

Procedure: The disc-shaped specimen was fitted into the specimen holder on the testing machine and was supported on its ends. It was then subjected to a transverse force by applying the load with a 2.00 mm thick rounded edge blade across its diameter. Loading was performed at a constant linear load rate. A load-cell electronically sensed the specimen failure, digitally displaying the results. The maximum load to failure was recorded. The complete test procedure is detailed in the AFS Mold and Core Test Handbook.

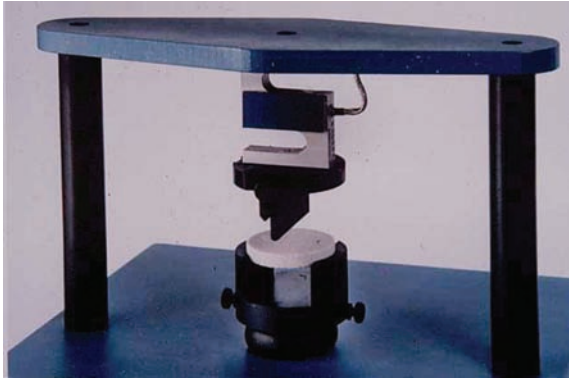


Fig. 2: Disc transverse strength (DTS) tester

2.4 Impact testing

An impact testing machine (Tinius Olsen) equipped with a disc specimen holder was used to measure the toughness of the sand specimens prior to and after the TDT. Impact strengths before TDT relate to handling of the core/mold material after core/mold production and prior to pouring. The impact strengths after TDT testing relate to shakeout/collapsibility characteristics.

The disc-shaped specimen was supported on its edge on a specimen holder on the impact testing machine (Fig. 3). It was then subjected to impact energy by dropping a uniform load with a 2.00 mm thick rounded edge blade across its diameter. A load-cell electronically sensed the specimen failure, digitally recording the results. The maximum energy to failure (Joules) was recorded.



Fig. 3: Disc-shaped specimen on holder at impact

2.5 Modified permeability

Permeability and Mold Quality Indicator tests were performed to provide a measure of the specimen's venting characteristics.

Equipment: A Gerosa Simpson permeability tester (Fig. 4), Disa George Fisher Mold Quality Indicator (MQI) (Fig. 5), a specimen holder designed and fabricated at WMU (Fig. 6).

Permeability is a measure of gas flow through a porous media, such as a sand mold or core. It was calculated for each specimen by use of equation 1.

$$P = (V \times H) / (P \times S \times T) \quad (1)$$

where:

- P*: Permeability
- V*: Percolated volume (ml)
- H*: Height of test sample (cm)



Fig. 4: Permeability tester with accessory attached



Fig. 5: MQI with accessory attached



Fig. 6: Specimen in gasket within holder accessory

P: Air pressure ($\text{g} \cdot \text{cm}^{-2}$)

S: Area of sample (cm^2)

T: Time in minutes

The permeability of a sand mold or core is affected by several factors including the size, shape, distribution, and method of compaction of the sand in the mold or core box. Furthermore, permeability is directly affected by the quantity of resin in the sand. Permeability testing is very common in the foundry industry and is part of the sand control tests performed on a regular basis at most foundries. A Gerosa Simpson permeability tester (Fig. 4) was used to perform the permeability tests conducted in this experiment. The specimen holder was designed and fabricated at WMU. A special rubber gasket was used between the specimen and the holder to provide a seal.

Additionally, a plug was used to restrict the airflow in order for the Gerosa Simpson machine to detect the permeability of each specimen.

The Mold Quality Indicator (MQI) test, which is inversely related to permeability, was also studied. The MQI number is a measurement of the resulting backpressure developed from the resistance of airflow through a mold or core. The MQI unit (Fig. 5) was equipped with an air pump, air tubing, and a rubber/foam contact head connected to the end of the tubing. An MQI unit is typically deployed somewhere along the molding line to perform real time measurements on the molds waiting to receive the molten metal. With some modifications to the original rubber contact head, this instrument was utilized with the WMU specimen holder.

Procedure: The specimen was secured into a holder (Fig. 7), which was then fixed to the permeability tester. The test was then started and the permeability measured. The holder with the specimen was then removed and attached to the MQI unit for measurement.

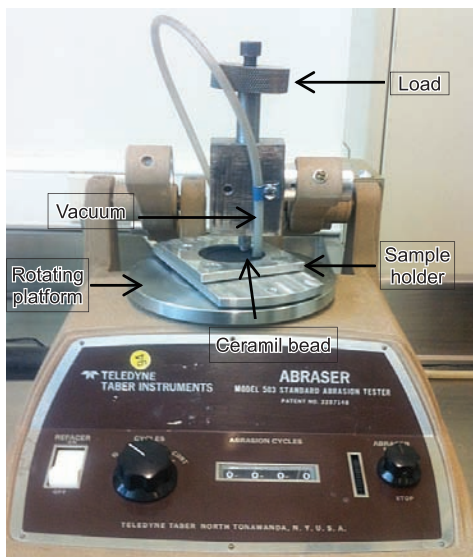


Fig. 7: Abrasion tester

2.6 Abrasion test

Abrasion resistance defines the property of a material surface to resist wear while in contact with another material. The determination of the abrasion/wear resistance of a cured surface layer plays a vital role in the estimation of effect on sand mold surface due to handling procedures. This test method encompasses ability to compare strength for different sand specimens against scratch or wear caused by handling.

Equipment: Teledyne Standard Abrasion Tester Model 503 equipped with a custom sample holder for disc specimens (Fig. 7).

Procedure: The 50 mm dia. × 8 mm thick disc-shaped specimens were weighed and secured onto the sample holder using four screws, one at each corner. The sample holder was mounted onto the abrasion tester with a ceramic bead pressing against the specimen surface perpendicularly as shown in Fig. 7. A desired load was applied onto the ceramic bead by mounting corresponding circular weights on top of the abrading

assembly. The specimen was then rotated in clockwise direction maintaining a constant rotational speed for a desired number of cycles/rotations. To ensure the proper contact between the ceramic bead and sand specimen surface, a vacuum was applied continuously to pull any loose sand particles during the test run. Reweighing the specimen and calculating the weight loss or percent weight loss then determined the abrasion/wear resistance of the specimen surface.

$$c = a - b \quad (2)$$

$$\%c = (c/a) \times 100 \quad (3)$$

where:

a: Initial weight (g) of specimen

b: Final weight (g) of specimen after test

c: Total weight loss (g)

The sand specimens were tested for 10 cycles/rotations with a load of 250 g on the ceramic bead and thereafter calculating weight loss and percent weight loss as defined in equations 2 and 3.

2.7 Thermal distortion testing (TDT)

TDT has the capability to represent the heat and pressures that sand binder systems, will experience from molten metal filling and solidifying in a mold. The word “represent” must be emphasized since molten metal has never been used with the TDT, and there is no exact simulation of casting condition during the test.

Operating conditions of the TDT device are like those where a mass of molten metal is pressing against the mold wall in a pseudo-static state. The load (metallostatic head pressure) on the specimen is held constant, and the specimen can only move into or out of the face of the hot surface depending on whether the specimen is expanding or plastically deforming (Fig. 8). Holding the temperature of the hot surface constant during testing simulates the mass of molten metal.

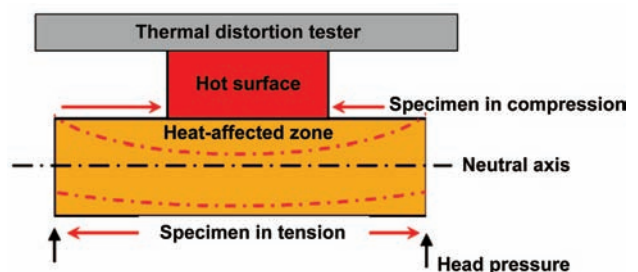


Fig. 8: TDT stresses on specimen

All of the functionality of the device is accomplished through the use of several instruments, controllers, mechanical devices, and a computer that is used to record data. The description of these features follows below.

Load calculations: A disc-shaped specimen receives a load about the circumference of one side as the other side is pressed onto a heated metal surface. Dividing this total load by the area of the heated surface approximates pressure. Thus, varying the load emulates a metallostatic pressure while controlling the metal surface temperature^[4].

Loading mechanism: The loading mechanism allows for the approximation of metallostatic pressures during the mold

filling and solidification of a casting. For better control and quantification of the resulting distortion, a uniaxial pressure load needs to be applied. This is accomplished by a free floating linear bearing slide that is coupled with an electronic actuator to provide the movement. The slide ensures that center axis of the specimen comes into contact with the center axis of the heated surface. The specimen is loaded into a ceramic tray. The tray locates the specimen against two pins. In addition, the tray is recessed so that any thermal-mechanical movement that takes places will not be restricted.

To prevent any shear forces from acting on the specimen surface in contact with the heater, a two-axis gimbal was used. The gimbal used three separate rings, one ring was fixed to the linear slider while the remaining two rings were allowed to rotate on two axes, each of which was 90 degrees from each other and oriented 90 degrees to the heated surface axis (Fig. 9).

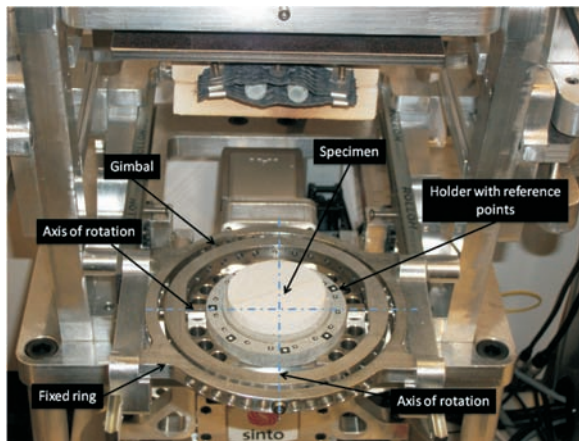


Fig. 9: Gimbal assembly

The axes for this gimbal system are centered at the face of the specimen. This prevents scuffing might occur when the specimen experienced uneven distortion since a static fluid would not create a shear load on a mold wall.

Heat source: To provide temperatures that simulate molten metal, a direct current power supply was wired in series with resistive heating elements. These elements pass through the heater mass/tip made out of MAR 247 (a super alloy). The utilization of a large heated mass has the purpose of assuring that the 90 second test is conducted with as constant of a temperature as possible. The heater is enclosed in insulation to direct the heat to the specimen. To account for thermal expansion of MAR 247, the insulated enclosure is allowed to move freely in the longitudinal and radial direction.

Instrumentation: This version of the TDT uses a variety of devices to collect data and control the heating process. The data that is acquired during each test is radial and longitudinal deflection, temperature at the hot surface and backside of specimen, and time. Longitudinal deflection in the specimen is tracked using a real time feedback loop within a commercial controller. The controller software uses the load as a reference and maintains the set value by changing the position of the actuator. To track radial movement, the TDT uses a green light camera system. This system uses the green light to create a shadow of the specimen so that the read-head can measure specimen

diameter. The temperature of the hot surface is sensed by a K-type thermocouple. To measure the temperature on the backside of the specimen, a non-contact infrared device was used. Time is recorded based on the sampling rate of the data acquisition system. All the temperature and movement signals are fed back to a data acquisition system that is attached to a personal computer (PC). Data is analyzed, stored, and displayed for each test.

Procedure: To operate the TDT (Fig. 10) the temperature control was adjusted to 1,000 °C (1,832 °F) to represent the cast iron-sand mold interface.

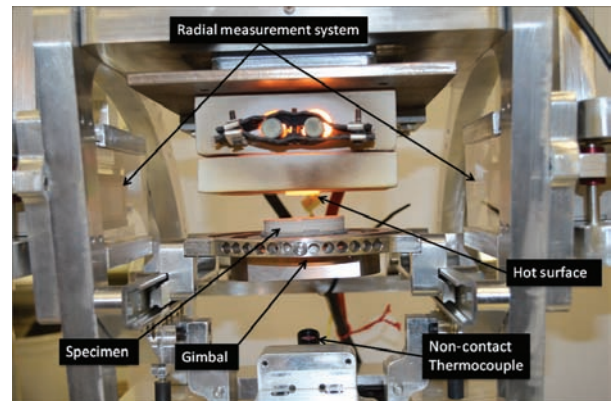


Fig. 10: Thermal distortion tester (TDT)

To simulate the force of molten metal to a 6 in. (15.24 cm) head height for cast iron with a density of 0.25 lb/in³ (6.92 g·cm³) providing a head pressure of 1.50 psi (0.01 MPa) (Head Height × Metal Density), actuator on the TDT was adjusted to a predetermined load of 331 g. The predetermined load was chosen for the test on the basis of the weight calculated to represent a 6 in. (15.248 cm) cast iron head height (contact area of TDT hot surface × head pressure), representing a head pressure typical of a medium sized iron casting.

The temperature at the hot surface was controlled using a K-type thermocouple and controlling, monitoring and plotting graphs of temperature/time versus distortion being performed by using an integrated computer peripheral and data acquisition system. The disc shaped specimen was mounted onto a pivoting holder (Figs. 9 and 10) and the specimen was automatically raised to achieve a symmetrical contact with the 2.00 cm (0.787 in.) diameter hot surface. A linear voltage displacement transducer (LVDT) was engaged at this point, which simultaneously engaged a laser to measure the distortion in longitudinal and radial directions. The distortions versus time/temperature curves were generated using the integrated data acquisition system. The thermal distortion tests were performed over a 90 second interval, being based upon the recommendations from a committee of foundry experts.

For the longitudinal distortion it is possible to differentiate between expansion (D_E) and plastic distortion (D_P) separately from the thermal distortion curve (TDC). In this investigation, the authors chose to record the total distortion (TD) and simply state:

$$TD = \Sigma D_E + \Sigma D_P \quad (4)$$

Further, the distortion radial (D_R) indicating expansion was monitored using a high speed laser micrometer scanning sensor

(resolution of 0.05 μm). Detailed procedure for the TDT has been defined in AFS transactions.

Prior to TDT, each specimen was weighed. Following TDT the surface of the specimen was blown with 20 psi (0.14 MPa) air pressure to remove any loose sand grains. The specimens were then again weighed, and the percent change in mass was recorded. Following weighing, the specimens were visually examined looking for signs of thermally induced cracking of the surface, loss of sand where contact was made with the hot surface, and any other discolorations or visual changes. If the core/mold media breaks down, this may be indicative of the tendency to produce cuts and washes, erosion/inclusion type defects. In interpreting this data, it is critical to identify the components causing the change in mass. The percent change in mass was calculated based upon the weight before and after as a percent of the weight before.

Change in mass: Prior to TDT each specimen was weighed. Following TDT the surface of the specimen was blown with 2 psi (0.014 MPa) air pressure to remove any loose sand grains. The specimens were reweighed, and the percent change in mass was recorded. Then the specimens were visually examined for signs of thermally induced cracking (veining) of the surface, loss of sand where contact was made with the hot surface, and any other discolorations or visual observations. If the core/mold media breaks down, this may be indicative of the tendency to produce cuts and washes, erosion/inclusion type defects. In interpreting this data, it is critical to identify the components causing the change in mass. The percent change in mass was calculated based upon the weight before and after as a percent of the weight before.

2.8 Quick loss on ignition

The loss-on-ignition (LOI) is the difference in weight before and after ignition of the sand sample. LOI is performed at an AFS-defined temperature or at metalcasting temperature, (e.g. cast iron requires a 2,600 °F (1,427 °C)). The main method for determining LOI involves heating samples to a temperature at which organic materials volatilize and decompose. The resulting loss in weight from the sample is the LOI measurement. LOI measurement indicates the amount of combustibles in raw sand. In chemically bonded sand, they absorb binder and reduce its effectiveness. Thus, LOI measurements can provide essential information about the overall quality of a foundry's sand system.

Foundries depend on a test of combustibles (LOI) to help manage their new sands, green sand systems, chemically bonded cores and molds, sand additives, and reclaimed sands. Each application has an established control range. The testing procedures defined by the AFS (Mold & Core Test Handbook) calls for use of either a muffle or microwave furnace. Unfortunately those tests are considerably slow. The time lag between testing and results can allow certain sand related defects if high levels of organic materials are present in foundry sand systems. A fast LOI test will allow foundries to identify the organic materials in sand in real time^[5].

Procedure: (Fig. 11)

(1) Turn on the computer data acquisition and induction LOI

tester;

(2) Weigh 3.00 g sample (sand dried at 200 °F (93 °C)) into crucible using an analytical balance;

(3) Place crucible with sample on ceramic support of the induction LOI tester;

(4) Position crucible with sample into the induction coil;

(5) Test (heating up to 2,000 °F (1,093 °C)) and data acquisition starts, logs data, and stops automatically after five minutes or no further mass change;

(6) Remove sample and cool;

(7) Interpret the LOI curve for results.

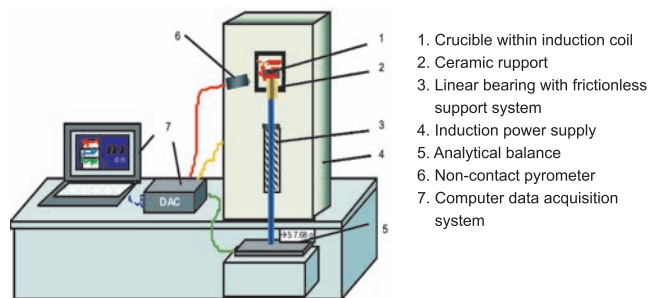


Fig. 11: Schematic of induction LOI testing system

3 Results and discussion

Chemically bonded sand test results are shown in Table 2. Though there was on significant differences in specimen weight there were differences in properties. The LOI results indicated the chemically bonded disc-shaped specimens were produced to target. The 1.4% PUCB samples were stronger and tougher in ambient conditions.

TDT results are shown in Table 3. All specimens were tested at 1,000 °C (1,832 °F). TDT and percent change in mass results are presented according to percent PUCB binder in each sample (Table 3). In addition, TDC, temperature versus time plots and picture information related to the systems are presented in Figs. 12 and 13 and Tables 3, 4 and 5.

3.1 TDT

The TDCs for all systems tested showed undulations that indicate thermo-mechanical and thermo-chemical changes in the binder system at elevated temperature^[2,4]. The longitudinal distortion curves all showed an initial expansion (upward movement of a TDC) before plastic deformation (downward movement of a TDC) (Fig. 12). The radial distortion (DR) clearly indicated an expansion trend (Fig. 12).

For specimens tested at 1,000 °C (1,832 °F), there was expansion for ~ 15 seconds followed by plastic deformation for the duration of the test. All specimens had similar TDCs and the two binder levels (0.9% and 1.4%) were not significantly different (Fig. 12, Table 3). This finding is supported by the temperature versus time data (Fig. 13).

3.2 Mass change

There are considerable heat induced thermo-chemical reactions occurring in both PUCB samples as is evident from the surface cracks found on tested specimens and percent change in mass

Table 2: Summary of test results of PUCB samples

	0.9% PUCB		1.4% PUCB	
	Mean	σ	Mean	σ
Specimen weight (g)	24.35	0.26	24.87	0.34
DTS (#)	30.57	1.67	35.38	2.23
Impact strength (J)	0.39	0.08	0.44	0.07
Permeability (#)	179	2.32	171	2.56
MQI (#)	114	1.76	120	2.40
Abrasion (% loss)	4.67	0.66	2.13	0.71
LOI (%)	0.86	0.12	1.35	0.25

Table 3: Thermo-mechanical properties of PUCB samples

PUCB sample	Results of thermal dist. testing at 3.25 N for 90 s				Elevated temp. testing	
	D_E Longitudinal (mm)	D_p Longitudinal (mm)	TD Total Longitudinal dist. (mm)	D_R Radial dist. (mm)	Change in mass%	Cracks and fractures
0.9	0.069	0.113	0.182	0.220	8.7	faint
1.4	0.051	0.107	0.158	0.234	1.6	large

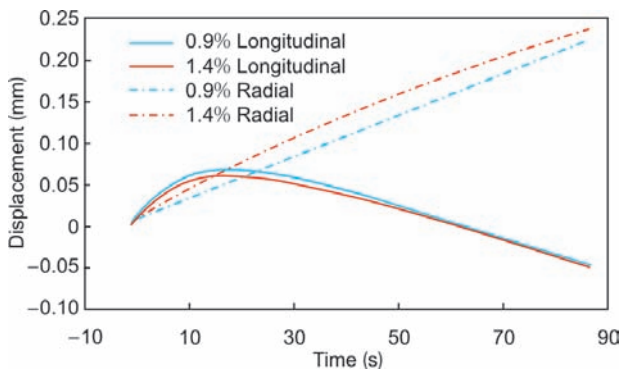


Fig. 12: Longitudinal and radial TDC for 0.9% and 1.4 % PUCB specimens

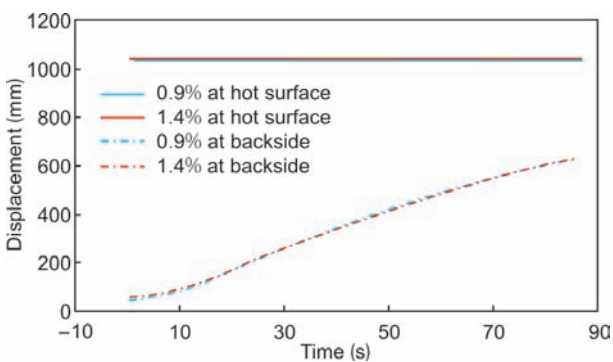
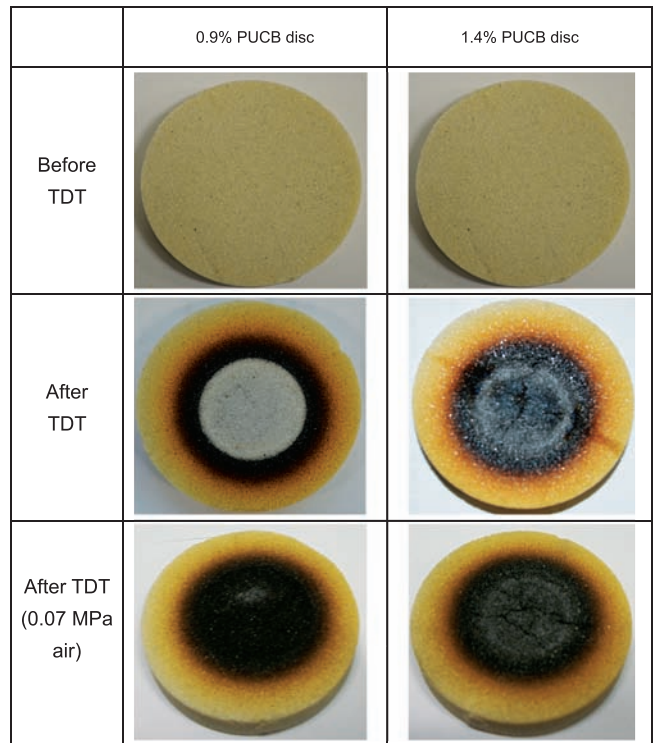


Fig. 13: Temperature versus time plots between hot surface and back of specimens

values (Tables 3 and 4). Expansion cracks were macroscopically evident on certain specimens. The crack propagation was more pronounced in 1.4% PUCB specimens (Tables 3 and 4). As was observed with the original TDT craters were evident at the hot surface/specimen interface where binder bridges pyrolyzed and sand grains broke loose. The percent change in mass for all systems tested is shown in Tables 3 and 4. The 0.9% PUCB specimens had more mass losses when compared to the 1.4% PUCB specimens (Tables 3 and 4).

Table 4: PUCB specimens before and after TDT



Observations from the heat-affected zone of specimens tested are shown in Table 4. The hot surface/specimen interface showed a crater with black discoloration due to binder degradation, the discoloration was present on the opposite side of the specimen. This indicated that there was significant heat transfer across and through the specimen (Fig. 13). In addition, sand binder losses were evident at the hot surface/specimen interface where binder bridges pyrolyzed and sand grains broke loose. The loose sand at the hot surface/specimen interface was white. Expansion cracks were macroscopically evident on the specimens.

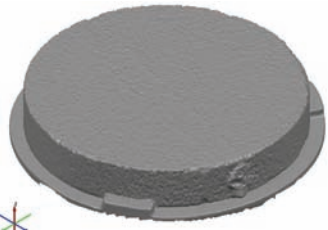
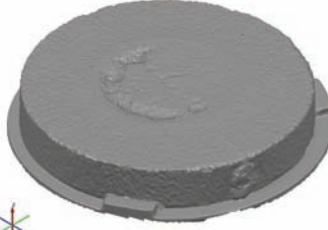
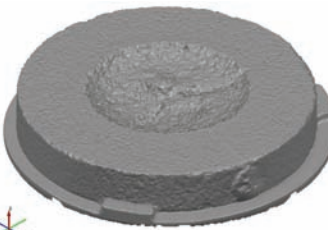
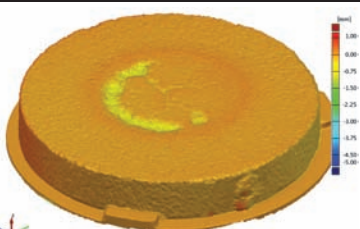
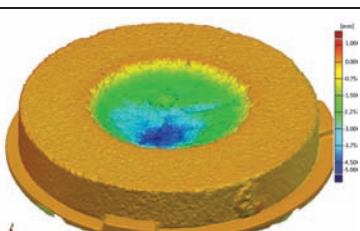
3.3 Total surface deviation

Observations were made macroscopically and supported with photographs and images from an ATOS II white light scanner [6]. Comparing surface deviation is achieved by alignment of the disc-shaped specimens before and after TDT. The specimen holder incorporates a set of reference points (Fig. 14). As long as the sample is not moved in the holder, the surface deviation can be tracked at each stage of testing.

Table 5 shows images from an ATOS II white light digital scanner [6]. The first three gray images show a specimen's surface as it sat in the holder before TDT, immediately after TDT, and after the loose material was blown away. Scans were taken at each step.

The three images were used to develop deviation plots. The specimen surface before TDT was set as reference and the other two surfaces were analyzed for deviations from the reference. The color plots show these deviations. The same deviation scale was used for both color plots. The holder at the base of the specimen shows no deviation and most of the specimen's surface shows little deviation with the exception of the region which was in contact with the hot surface.

Table 5: Digital images of a PUCB specimen before and after TDT

Description	Scanned Images
Before TDT	
After TDT	
After TDT - and 0.07 MPa air blow	
Deviation plot After TDT	
Deviation plot After TDT - and 0.07 MPa air blow	

4 Conclusions

The DTS, impact, permeability, MQI, abrasion, LOI and thermal distortion tests results indicate that there is relatively lower test-to-test variability with the disc-shaped specimens. The non-standard tests were able to discriminate between the chemically bonded PUCB sand specimens.

The thermo-mechanical changes brought forth are in the forms of TDC, mass loss, and cracks on the surface of the test specimens. There was no difference in distortion (longitudinal and radial) between the 0.9% and 1.4% PUCB specimens at 1,000 °C (1,832 °F) with a 3.25 N (0.73 lbf) load representing 15 cm (6

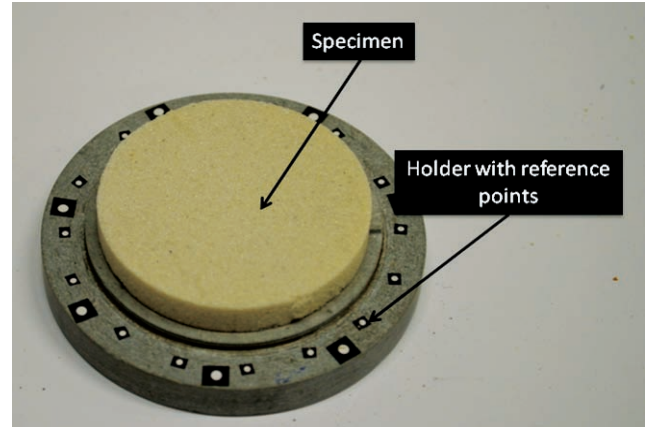


Fig. 14: Gimbal assembly with reference points incorporated into holder

inch) cast iron metallostatic head pressure.

The elevated temperature and pressure did promote distortion on the PUCB specimens. The TDT was able to capture and record both longitudinal and radial distortion curves. Further, time versus temperature data across the specimen was acquired. Heat transfer and thermal gradient information is important input data for solidification simulation programs.

It is important to recognize that because the disc-shape specimen is simple in geometry it can be easily incorporated at the core box/tool parting-line and vented to produce disc-shaped specimens in core/mold production. This would not be easily achieved using the standard dog bone tensile or transverse tensile specimens. Supplementary, the disc-shape specimen offers the opportunity for much more than mechanical testing. Disc-shape specimens are also used in testing physical and thermal properties of chemically bonded sands and casting trials have been developed for this specimen type^[4].

Further studies should be conducted on various other sand and binder systems as well as on different specimen thicknesses.

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