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# Comparing Hot Friability Test Data to Results from a Green Sand Erosion Casting Trial

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## ABSTRACT

Casting issues at a sand/metal interface can result in costly defects. The greatest proportion of sand/metal defects occurs with green sand erosion being prominent. Sand in the foundry industry no longer means just silica and specialty sands. Today, several other materials both natural and synthetic are candidates for replacing silica sand. A non-standard hot friability test (HFT) has shown potential in measuring thermal durability of green sand. This paper addresses green sand erosion and surface finish issues for iron castings. Green sand erosion can occur when molten alloy dislodges grains of sand, resulting in a rough as-cast finish.

A casting trial was developed and tested to evaluate erosion on multiple green sand specimens simultaneously. A gray cast iron recipe was delivered from a controlled head pressure and temperature to achieve a turbulent flow across green sand specimens prior to solidification of the casting. Flow and solidification simulation of the erosion casting trial model was conducted to verify turbulent flow of iron over specimens. Results show that there are surface differences among the green sand systems studied.

**Keywords:** alternative molding media, ceramic sand, foundry sands, green sand, properties, specialty sands, casting defects, sand erosion defects, casting surface finish.

## INTRODUCTION

### BACKGROUND

This paper enhances findings from a *2022 AFS Transactions* paper (#22-012): "Comparing the Green Properties for Silica, Chromite, and Ceramic Sands using AFS Baseline and Non-Standard Dynamic Tests."[1] The previous study identified the AFS standard baseline properties of silica, ceramic and chromite green sand systems at equal clay concentration; density differences were not considered. Furthermore, hot friability testing (HFT) was able to differentiate among various green sand systems for the same compactability level (moisture content) and clay level.[1,2] This paper focused on sodium bentonite (75%), calcium bentonite (25%) blend at 35% compactability that is typical in cast iron foundries. The dynamic tests provided more relevant data about these green sand systems compared to the baseline tests.[1]

The ceramic sand labeled "AA," is synthetic because the original media was heat processed. The chromite and silica sands are natural mineral and labeled "BB" and "CC" respectively. Table 1 is used to identify the granular media used in this study by letter and color coding. Additionally, the chemical analysis, properties and characteristics are shown.

Apart from the raw granular media data that is presented in Table 1, additional data regarding physical properties of sand size, distribution, shape, surface area, density and chemical properties such as moisture, pH and acid demand value are available in the previous paper.[1] This study provides data for determining if a candidate granular media will function satisfactorily in a green sand erosion casting trial. For this reason, the results of this study will be compared to the HFT data found in *AFS Transactions* Paper 22-012.[1]

It is important to point out that in 2022, Minerals Technologies Inc. (MTI) Hoffman Estates Laboratory assisted Western Michigan University (WMU) in the previous project by mixing and blending the green sand samples.[1] The casting trial presented in this paper is an extension of that project. Thus, mulled green sand samples of a ceramic, chromite, and silica molding media was prepared at MTI to 8% active clay using a combination of 75% sodium bentonite and 25% calcium bentonite. It should be noted that no carbonaceous material was added to the mix. The samples were shipped to WMU Metal Casting Laboratory for green sand evaluation.

HOT FRIABILITY TEST (HFT)

Most of the defects in sand casting facilities are sand related, but many metalcasters fail to recognize that molding sand quality is as important as metal quality.[3,4] A comprehensive discussion about green sand testing and process/quality control has been covered in a number of AFS publications.[1–4] The testing procedures are defined by AFS.[5] The AFS friability test measures the bulk brittleness of the sand at ambient condition, and is related to erosive losses in green sand molds.[1,2,5] The friability test shows an inverse relationship between erosive loss and moisture content and percent compactability of green sand. The main drawback of the friability test is relating the two Standard AFS specimens rotating in a cage to the erosive flow of molten metal. A better approach can be the hot friability test (HFT).[1,2] The test uses a rotating Standard AFS specimen against a hot surface where the eroded sands are measured in real time. This test helps to identify the thermal durability of a green sand sample.

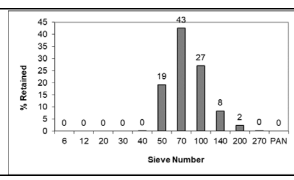
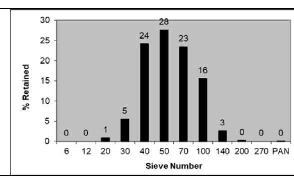
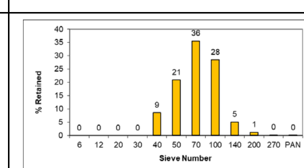
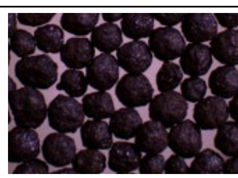
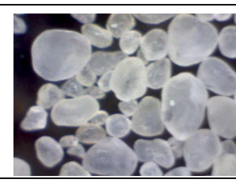
| Granular Media → Chemical Analysis (%) | AA | BB | CC |
|---|---|---|---|
| $Al_2O_3$ | 74 | 14.97 | 0.13 |
| $SiO_2$ | 7.8 | 0.44 | 99.7 |
| FeO | 13.05 | 25.96 | 0.10 |
| $TiO_2$ | 1.8 | - | < 0.01 |
| MgO | - | 10.41 | < 0.02 |
| $Cr_2O_3$ | - | 46.66 | - |
| **Properties** | **AA** | **BB** | **CC** |
| AFS Grain Fineness | 56 | 45 | 56 |
| pH | 6.9 | 7.2 | 6.8 |
| LOI (%) | 0.01 | -0.58 | 0.05 |
| Bulk Density (g/cm$^3$) | 2.30 | 2.92 | 1.96 |
| Shape | Round | Sub-angular | Rounded |
| Sintering Temperature (°C) | 1445 | 1368 | 1463 |
| Screen Distribution |   |   |   |
| Pictures (100X) |  |  |  |
| Base Material | Sintered Bauxite | Natural | Natural |
| Color | Dark Gray | Black | White/ Light Tan |
| Surface of Grain | Uneven | Smooth | Smooth |

*Table 1. Types of Granular Media, Composition, Properties and Characteristics*

## EROSION IN GREEN SAND

In the foundry industry, there can be many types and causes of metalcasting defects.[3,4] These casting defects can be related to the alloy and/or the mold/metal interfacial issues. There are several publications dedicated to identifying causes for these defects. Casting issues at the sand/metal interface result in defects such as: inclusions, veining, penetration, scabs, scars, erosion, etc.[3,4] Moreover, the greatest proportion of sand/metal defects occurs with the green sand process.

Erosion defects are major concerns with any casting process involving bonded sand.[1-4] Erosion usually occurs within the gating system and/or at a mold-metal interface of the pattern cavity. Green sand erosion is caused when the molten alloy dislodges grains of sand resulting in a rough as-cast finish. This defect is associated with turbulent metal fill. This phenomenon of high velocity pouring can cause surface defects on the casting. The reasons for erosion defects are due to one or a combination of the following: design, raw materials, molding and filling technology. Poor sand characteristics such as reactive contaminants, weak green sand properties, turbulent metal flow, head pressure, cross-sectional area of the gating system and molding technology are examples that can lead to erosion defects.[6]

Erosion phenomenon is the relation between a stationary entity and fluid flow. In other words, it is the defect caused by the kinetic energy of fluid flow. A sand mold remains stationary while molten metal flows inside the cavity with some definite momentum. This impetus can dislodge sand particles. When the bond between two particles breaks, because of flow momentum a lift occurs, and it removes these particles from the surface. This progression causes cavities on the mold surface that leads to surface roughness.[6]

Solidification simulation is a valuable tool in the metalcasting industry. It can be used to predict casting defects. Simulations are mainly used for design and sometimes for manufacturing problem solving. Nowadays the metalcasting industry is using solidification simulation software to predict casting quality and defects, such as sand erosion. The rational for using this approach would be to identify casting design issues such as turbulence and detect metallurgical concerns prior to actual production.[6]

This study compares HFT data from lab green sand testing to a casting trial model developed at WMU. The aim of the simulation is to determine if there are erosion tendencies among various green sands with same active clay level, grain size (GFN) and percent compactability.

## NEED & PURPOSE

There is limited information regarding green properties of alternative and specialty molding media being used in the foundry industry. The purpose of this study is to determine if the non-standard HFT data from ceramic (AA), chromite (BB), and silica (CC) green sand can be related to data from an erosion casting trial.

## OBJECTIVES

Compare the HFT of green sand systems AA-CC at the same clay level and compactability and determine if there are differences from an erosion casting trial. The aim will be to measure the surface roughness at a cast iron/green sand specimen interface for various green sand systems AA-CC and compare it to HFT data.

# METHODOLOGY

An experimental model was designed to perform a casting trial on three green sand specimens and a shell sand specimen (DD) was used as a control. The shell sand material was a finer 80 GFN, 3 screen system with 4% resin based on sand (BOS) selected as a molding material that is resistive to the erosive flow of molten metal. The specimens were positioned at mold runner/metal flow interfaces to experience the turbulent flow of gray iron during casting.

The methodology was divided into three areas:

1. Preparation of green sand test specimens and a control specimen;
2. Gray iron casting trials; and
3. Data gathering, observation and analysis.

## SAND SPECIMENS

The three green sand systems (AA-CC) were mulled to temper and target compactability. The AFS Standard specimens were prepared according to *AFS Transactions* Paper 22-012.[1,5] Figure 1 shows the green sand specimens and the control specimen (DD).

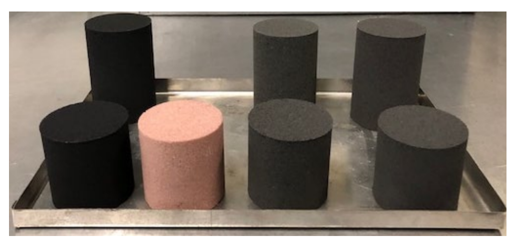


***Figure 1. AFS Standard 2 x 2" specimens are shown in the foreground (left to right CC, DD, BB, and AA) with the associated AFS Standard compactability specimens in the background.***

## CASTING TRIALS

The casting trial consisted of the following steps:

i. model design and simulation,
ii. development of an experimental matchplate pattern,
iii. preparation of a chemically bonded sand mold,
iv. principle of the gating design, and
v. melting and pouring

## Model Design and Simulation

A model was developed where the green sand specimen/metal interface could be evaluated using a casting trial.[6] Chemically bonded sand molds were built where the sand-to-metal weight ratio for all molds was 2.5:1. All molds were produced with a pouring sleeve and filter for constant head-pressure and fill velocity. Each mold contained four cavities with core prints but there was no positional effect to be assessed on the casting. This approach allowed possible variation in casting quality to be assigned to only the specimens.

Designing the model was the first step towards this research project. CAD software was used to generate an idea about the erosion model. In gravity casting technology, the value of fluid flow which can cause erosion is considered to be a minimum of 1 m/s (~40 inch/sec). Using simulation software, optimization was done on the CAD model to identify velocities higher than minimum. Altair Inspire Cast was used for simulating this model. Figure 2 shows a CAD design for the erosion model.

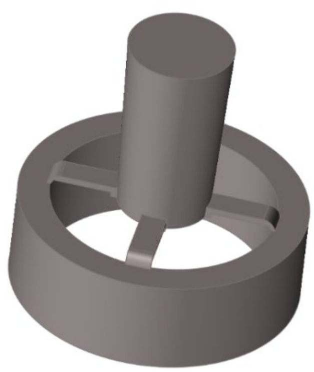


***Figure 2. CAD image of erosion model.***

Simulation software was used before actual casting trials. The purpose of this tool was to make predictions of some factors such as temperature, pressure, shrinkage etc. in the final casting. This prediction will allow the comparison of actual castings to obtain information for improving the design. Table 2 shows values obtained from simulation results.

***Table 2. Simulation Predictions***

| No. | Factors on runner surface | Values |
|---|---|---|
| 1 | Pressure | 0.1 (MPA) |
| 2 | Temperature | 1430 (℃) |
| 3 | Velocity | 1.5 m/s |

Figures 3 and 4 show the bottom view of analysis results taken from the simulation.

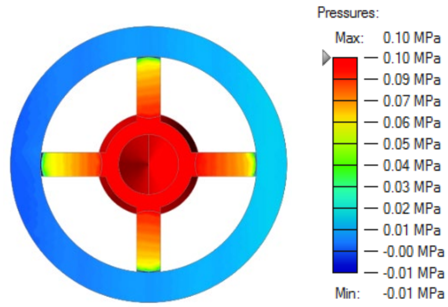



***Figure 3. Pressure generated during metal filling in simulation.***

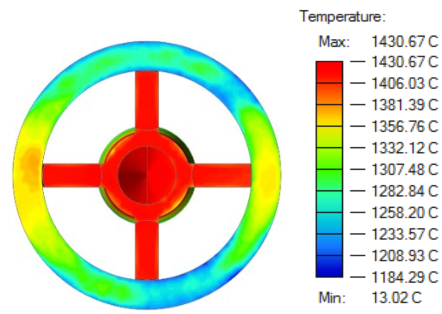



***Figure 4. Temperature distribution during metal filling in simulation.***

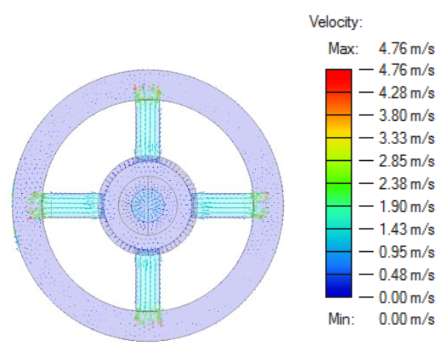



***Figure 5. Velocity obtained at various areas during metal filling in simulation.***

## Experimental matchplate

In this experiment, three different foundry green sand specimens (AA-CC) and a control specimen (DD) were compared using a matchplate to perform casting trial. The model was designed such that constant flow and a particular range of velocities could be achieved from a 6-inch (15 cm) head. The aim of the experiment was to determine any erosion issues that may occur at the cast iron/specimens interface.

This model includes a design of matchplate pattern, shell ceramic sand plate with runners and shell ceramic sand cone on the surface of the partingline. Fig. 6 - 8 shows the design of three important aspects of the models.

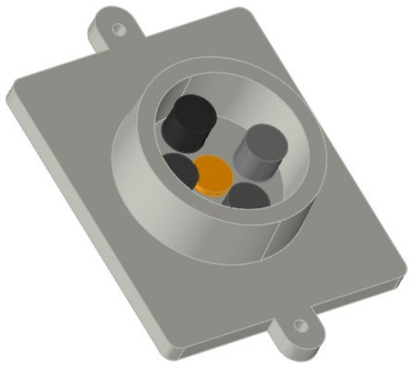


*Figure 6. Drag side of matchplate pattern.*

The drag side pattern (Fig. 6) was used to develop a drag mold. In the four cavities of the drag mold, AFS standard 2 x 2” sand specimens were arranged such that a small portion of their height (~4 mm) was raised above the parting line.

A cope mold with a sleeve was developed to receive a specialized shell sand core. The sleeve from the cope aligns with the shell sand core (Fig. 7) to simultaneously deliver the molten metal over the sand specimen surfaces (AA-DD).

*Figure 7. Shell sand core used to deliver molten metal over the specimen surfaces.*

The shell sand core was fitted onto the four sand specimens (AA-DD). A shell sand cone (Fig. 8) was affixed to the drag and symmetrical to the shell core prior to capping with the cope. A model of the mold assembly is shown in Fig. 9. It is important to point out that both the shell sand core and the shell sand cone were selected to protect the wetted surfaces against erosion during fill.

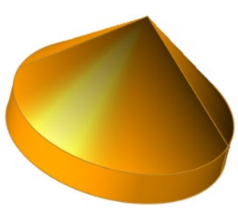


*Figure 8. Shell sand cone used to separate flow and encourage turbulence.*

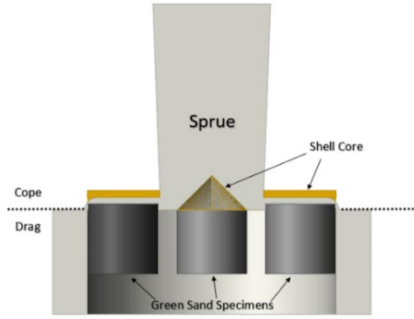



*Figure 9. Cross-section of the model showing an assembled mold.*

## Preparation of Chemically Bonded Sand Mold

The silica base aggregate (round grain silica sand, 55 GFN, 3 screen) used in the study came from Illinois. A phenolic urethane (Pep-Set and catalyst 3% BOS) binder system was applied via a continuous mixer. After the mold cured the pattern was stripped the mold runners were protected by a zircon refractory coating (90 Baume).

## Procedure

Mold halves were fabricated according to an experimental matchplate pattern (Figs. 6 and 7). The pattern cavity runners (4) were refractory coated so any sand issues at the specimen metal interface would be due to the specimens themselves. The drag mold with specimens set on coreprints is shown in Fig. 10. A 6-inch (15 cm) tall pouring sleeve was affixed to the cope as a sprue to deliver the metallostatic head. The central sprue pouring sleeve was without filter to encourage a turbulent fill.

*Figure 10. Drag mold with specimens on coreprints.*

## Principle of Gating Design

A pressurized gating design was used to control the fill of the casting (Fig. 11).[6] The gating ratio was Area of Sprue: Area of Runners: Area of Ingates and was measured 23.4: 1.0: 1.8 (area units are $mm^2/100$). This design allowed a constant fill time (~15 sec.) with the turbulent metal flow over the control and green sand specimens. This allowed the researchers to investigate potential erosion issues. The parameters of temperature, pressure and velocity of fill were discussed under the sub-heading “Model Design and Simulation on the previous page.”

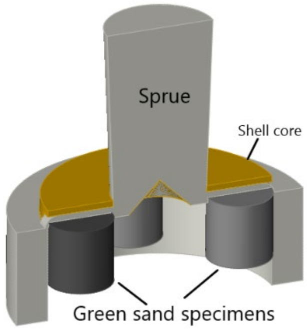



***Figure 11. Cut-section of erosion model showing gating design in relation to specimens.***

Melting and Pouring:
The mold was poured where the sand specimens (AA-DD) were set into the drag (Fig. 10). The drag mold contained four symmetrical cavities with no positional effect to be assessed on the casting. This approach allowed possible variation in casting surface quality (specimen/metal interface) to be assigned to the three green sand specimens and the control specimen. The sand-to-metal ratio for the casting was 2.5:1.

The mold was manually poured, and gray cast iron was (average pouring time = 15 sec., temperature at pour ladle = 1450C (2642F), CE = 4.06, C = 3.47, Si =2.17, and chill = 0.02”) delivered through a direct pouring sleeve fitted. The mold was poured to a 6-inch (15 cm) head-height. The metal chemistry is shown in Table 3. The mold was prepared and poured at Metals Technologies Inc., Three Rivers Gray Iron foundry. The casting was allowed to solidify under an ambient temperature. After air cooling and shakeout, the casting was sectioned near the specimen/metal interfaces.

***Table 3. Metal Chemistry***

| C | Si | P | S | Mn | Cr | Ni |
|---|---|---|---|---|---|---|
| 3.47 | 2.17 | 0.049 | 0.10 | 0.60 | 0.123 | 0.06 |

| Al | Cu | Ti | Sb | Fe | C.E. | Chill |
|---|---|---|---|---|---|---|
| 0.005 | 0.22 | 0.009 | 0.007 | ~93 | 4.06 | 0.02 |

## DATA GATHERING

After solidification and cool down of the casting, the next step was to shakeout from the chemically bonded sand mold manually. As-cast surfaces particularly the runners were gently cleaned using a wire brush. To evaluate the sand specimen surface and the as-cast surface (runners) a non-contact 3D-Macroscope was used. Using the 3D-Macroscope and its accompanying software, high-speed, high-accuracy 3D measurements of the surface finish were documented.
Before performing the actual casting trial, surface texture and roughness of the specimens (AA-DD) was measured using the 3D Macroscope. After the casting trial and shakeout, the as-cast runner interface was measured using the 3D Macroscope.

## RESULTS AND DISCUSSION

### AFS GREEN PROPERTIES AND HFT

The AFS standard green property data is shown in Table 4.[1] Tests were carried out on as-mulled green sand systems at a target compactability level (35%). The methylene blue clay and AFS clay provided information relating to the bond. The loss on ignition (LOI) indicated the percent carbonaceous material present in the green sand system. The AFS tests did not revealed much difference among the overall green properties.[1]

Table 5 shows that HFT was able to discriminate among the green sand system AA-CC. In hot friability testing (HFT) lower values means less abrasion (thermal erosion) loss. In terms of bulk surface abrasion resistance, using hot friability testing system BB was the best and system CC was the worst.[1]

***Table 4. Comparison of the Standard Green Properties for the Various Systems (AA-CC)[1]***

| Green Sand | | AA | BB | CC |
|---|---|---|---|---|
| Compactability (%) | | 35 | 35 | 35 |
| Wt. of Compact. Spec. (g) | | 213 | 265 | 154 |
| Moisture (%) | | 2.44 | 2.49 | 2.47 |
| 2" x 2" Spec. Wt. (g) | | 210 | 265 | 154 |
| Mold Hardness (B scale) | | 95 | 95 | 95 |
| Green Comp. Str. (psi) | | 28 | 28 | 27 |
| Dry Comp. Str. (psi) | | 47 | 47 | 38 |
| Splitting Str. (psi) | | 4.2 | 5.3 | 2.8 |
| Green Tensile (psi) | | 3.9 | 4.9 | 2.6 |
| Green Shear (psi) | | 9 | 10 | 9 |
| Available Bond (%) | | 6.15 | 6.22 | 6.09 |
| Working Bond (%) | | 4.41 | 4.41 | 4.25 |
| Muller Efficiency (%) | | 72 | 71 | 70 |
| Hot Comp. Str. (psi) | 1650 °F | 654 | 659 | 512 |
| | 1850 °F | 294 | 378 | 327 |
| | 2000 °F | 64 | 174 | 161 |
| Methylene Blue Clay (%) | | 8.3 | 8.3 | 7.5 |
| AFS Grain Fineness No. | | 56 | 45 | 56 |
| LOI | | 0.01 | -0.58 | 0.05 |

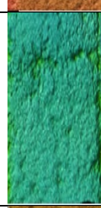
***Table 5. Comparison of the HFT for the Various Systems (AA-CC)[1]***

| Green Sand / Properties | AA | BB | CC |
|---|---|---|---|
| HFT (500°C 6 sec.) (%) | 1.23 | 0.66 | 1.59 |
| Ambient Friability (%) | 0.59 | 0.58 | 0.29 |
| HF Index | 1.34 | 1.08 | 1.27 |

## CASTING TRIALS

From observation taken after shakeout each runner specimen was wire brushed for image analysis and results are shown in Table 6. The as-cast surface was rougher compared to the corresponding green sand interface. As expected, the best as-cast surface finish was from the control System DD. It was interesting to find that System CC (silica green sand) was significantly rougher when compared to Systems AA and BB evidently due to erosion.

***Table 6. As-cast Metal Surface Analysis***

| Specimen | Specimen Surface Roughness (µm) | As- Cast Surface | As-Cast Surface Roughness (µm) |
|---|---|---|---|
| **AA** | 50 |  | 57 |
| **BB** | 53 |  | 55 |
| **CC** | 48 |  | 67 |
| **DD** (control) | 32 |  | 30 |

*Note: The lower values indicate a smoother surface*

## LIMITATIONS

This study focused on just three granular media that are being used in foundry green sand systems. Moreover, only one clay blend was applied to the granular media using laboratory equipment.

## CONCLUSION AND RECOMMENDATIONS

The hot friability test (HFT) was able to differentiate among the green sand systems AA - CC. Systems AA and BB showed superior green properties and hot friability resistance. Moreover, this work has identified that ceramic green sand system "AA" and chromite green sand system "BB" may provide superior properties to silica green sand system "CC" at equal clay concentrations based on the weight of granular media. The green sand systems AA and BB showed superior bulk surface erosion resistance at elevated temperature when compared to CC at equal clay concentrations.

All green sand systems tested showed some amount of erosion tendency after the casting trial but not all showed the same extent. The erosion casting trial for green sand show potential with as-cast surface roughness as a discriminant. Temperature and head pressure were kept constant for the casting trial experiment but these variables have an effect on as-cast surface quality. It is recommended that additional green sand systems be studied using varying fill temperatures and head pressures. Furthermore, casting trials using a volumetric change of the runner bar as a metric in determining erosion tendency should be investigated.

This study reinforces a need to study sand erosion with respect to HFT. An erosion casting can be used evaluate green sand durability and surface finish. The researchers believe that HFT properties of a green sand system along with casting trial temperatures, pressures, velocities during fill of an alloy can be integrated into solidification simulation software systems to better depict issues such as surface finish and sand erosion defects.

## ACKNOWLEDGMENTS

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