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NUMERICAL SIMULATION AND THERMOMETRIC MEASUREMENTS ON MOLD FILLING DYNAMICS

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ABSTRACT

In this paper we present the results of the CFD simulations of the mold filling dynamics in gravity and counter-gravity lost foam castings. FLOW-3D software package (Flow-Simulations, Inc.) has been used to predict flow velocity distributions and pressure losses when liquid metal flows in the step pattern. The results of simulations are compared to those obtained experimentally.

INTRODUCTION

The lost foam casting process is a technique for manufacturing complicated castings using an expandable polystyrene pattern and sand. In this process polystyrene patterns attach to a polystyrene gating system and a thin layer of a refractory ceramic coating material is applied to the entire assembling. After he coating has been dried, he foam pattern is attached to a downsprue to form a cluster which is imbedded in unbonded sand. The molten metal is then poured into the downsprue, and it vaporizes the gating and patterns. The molten metal displaces the styrofoam pattern with precise dimensional accuracy. Gases produced due to the vaporized polystyrene foam pass through the coating layer on the foam pattern and the compacted sand.

Counter-gravity vacuum lost foam casting is a good alternative to the conventional casting process, where the filling velocity of the liquid metal can be controlled without turbulence. This technique has recently emerged to improve the casting quality. Our previous studies showed numerous advantages of using vacuum assisted counter gravity casting (Bakhtiyarov et al., 2000).

In this paper we present the results of the numerical simulations and experimental measurements of mold filling dynamics in gravity and counter-gravity lost foam casting.

EXPERIMENTAL SETUP AND PROCEDURE

A flask of volume 0.3 m^3 was used as a ladle in our casting experiments. The gating systems and the custom design step patterns were prepared by means of a hot-wire cutter from expanded co-polymer (blend of EPS and PMMA) blocks and sheets with density 0.02602 g/cm^3. Molten wax was used to assemble the pattern.

Sensor electronics were housed in special briefcase designed and built with safety and portability requirements of the foundry environment. All sensors were connected to a computer controlled data acquisition system through PC-LPM-16/DAQCard-700. Up to 16 chromel/alumel thermocouples were used in a single casting experiment. The thermocouples were connected to the computer controlled data acquisition system. In order to record the mold filling and solidification characteristics, the thermocouples were scanned every 0.01 s.

The assembled pattern with runner and gating system was coated by permeable refractory coating material. PolyShield P2325 (Borden Chemical, Inc.) refractory coating was used during the experiments. Rheological and thermal properties of this refractory coating material was investigated experimentally and the results are presented earlier (Bakhtiyarov et al., 1999). It has been determined that this coating exhibits non-Newtonian shear thinning and thermal thickening fluid flow behavior. It obeys the Casson rheological model over the shear rate range investigated. The parameters related to product performance and composition variations ("limiting high-shear viscosity" and "yield point") are determined as a function of temperature.

Dipping with refractory coating coated the pattern assembly and then it was oven dried at 60° C for 16-18 hours. As we know, the thickness of the refractory coating strongly affects the amount of gases escaped from the mold. Special experiments were performed to determine the permeability of the refractory coating PolyShield P2325 as a function of the coating thickness. Digital Absolute Permmeter (SIMPSON®/ GEROSA) was used to measure the permeability. As seen from the rersults, the thickness has a tremendous impact on the coating permeability. Therefore, it was very important to keep a coating thickness constant during the experiments.

The coated pattern was positioned on the sand base (5-7 cm). The thermocouples were positioned at the chosen locations, and then more sand was added and compacted by a vibration. Olivine sand with an AFS number of 35 was used in all the experiments. The density and porosity of the compacted sand were 1.5045 g/cc and 0.375, respectively.

Liquid A356 aluminum alloy was used to conduct experiments. The metal was melted in the ceramic crucible (0.02 m^3) by induction furnace, which used 20 kW power from the LEPEL® power supply. The temperature of the liquid inside the crucible was measured by the portable two-color infrared pyrometer (MIKRON® M90R-1).

Thermometric measurements for aluminum lost foam casting was conducted on clusters depicted in Figures 1 and 2, for gravity pouring and counter-gravity casting, respectively. Two step patterns (Figure 3) were vertically attached to a gating system consisting of a runner and a hollow sprue. The sprues had a shape of right cone frustum of 31.75 mm diameter at the bottom and 700 mm long. The locations of the thermocouples on the patterns are shown in Figure 1 and 2.

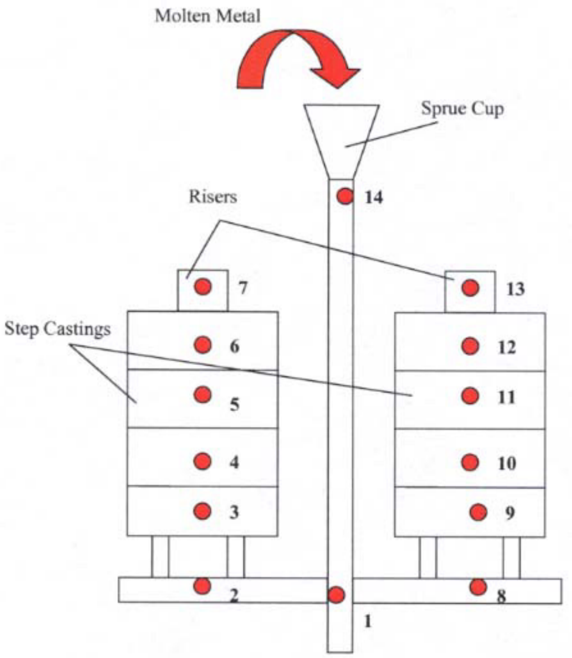

Figure 1. Pattern cluster used for gravity lost foam casting.

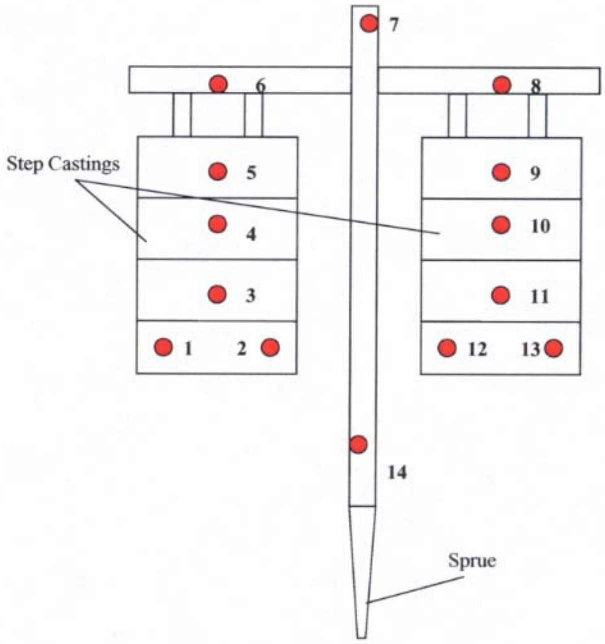

Figure 2. Pattern cluster used for counter-gravity lost foam casting.

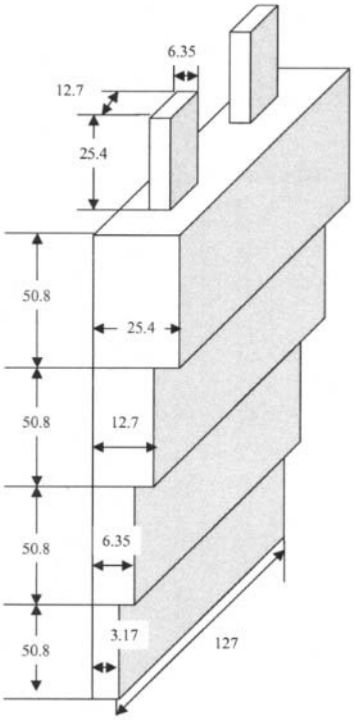

Figure 3. Step pattern used in casting experiments.

NUMERICAL SIMULATIONS AND RESULTS

We conducted 3-D numerical simulation of mold filling using FLOW-3D software package. A step pattern model proposed in the experimental studies was chosen for the simulations. A computational mesh consists of 80, 40 and 40 uniform computational cells distributed respectively in x, y and z directions. A line-implicit iteration was applied to minimize the numerical asymmetry in the solved problems. The iteration solves the pressures and velocities in each cell and minimizes small perturbations in both directions. The FLOW-3D includes a selection of subroutines in Compaq Visual FORTRAN source form that allow customizing Flow-3D. The results of simulations for counter-gravity mold filling are presented in Figures 4-8. As seen from these figures, thin sections are filled first It takes ~2 seconds to fill the whole pattern. FLOW-3D software package allows introducing into the stream the tracers, which does not disturb the flow parameters and pattern. The tracer remains as a dye streak while conforming to the convoluted motions formed by the coherent vortices as they evolve. Introducing the tracers into the mold flow allowed us to estimate a rate of dissipation of turbulent kinetic energy during both gravity pouring and counter-gravity casting techniques. Simulation results showed that the turbulent kinetic energy is higher in gravity pouring than in counter-gravity casting method.

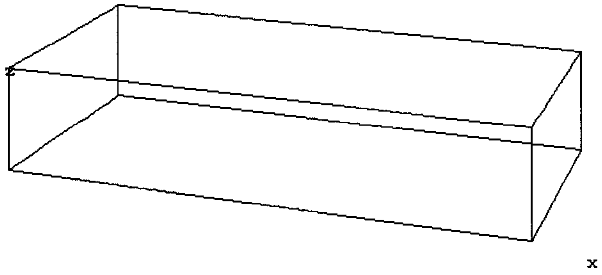

Figure 4. 3-D simulation of mold filling in step casting (t=0.0 s).

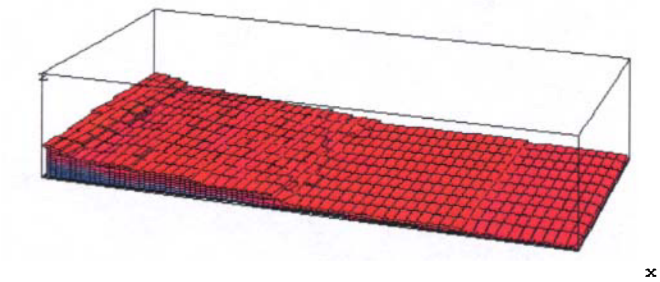

Figure 5. 3-D simulation of mold filling in step casting (t=0.5 s).

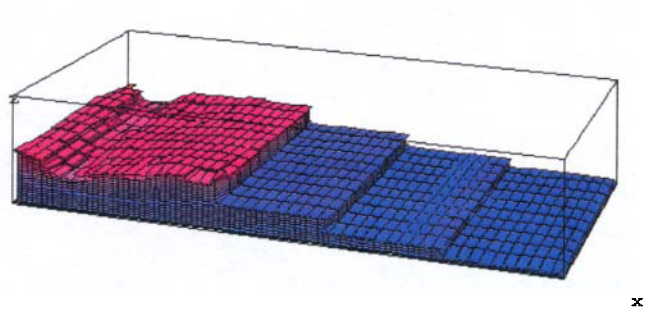

Figure 6. 3-D simulation of mold filling in step casting (t=1.0 s).

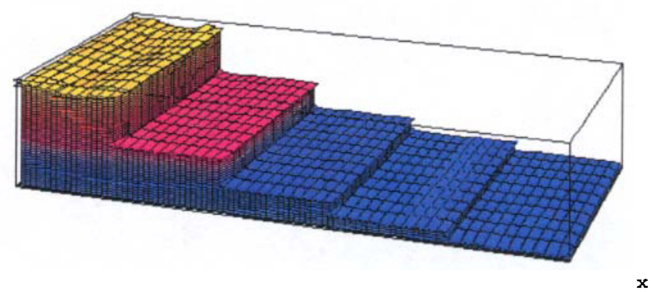

Figure 7. 3-D simulation of mold filling in step casting (t=1.5 s).

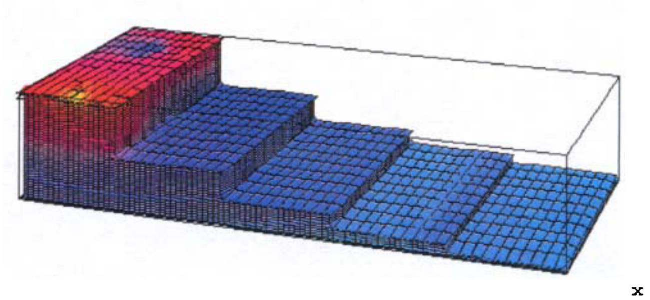

Figure 8. 3-D simulation of mold filling in step casting (t=2.0 s).

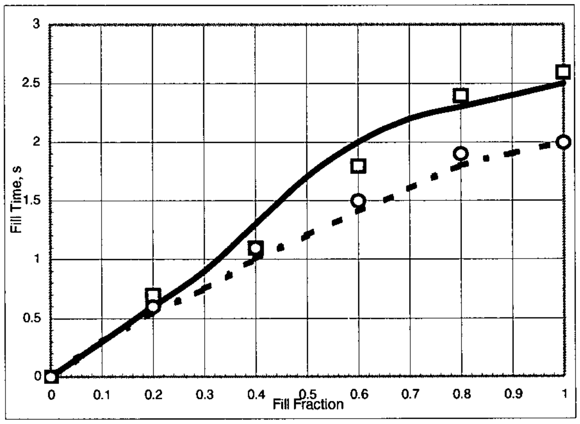

Figure 9. Variation of fill fraction with time (__Gravity, --- Counter-gravity)

Figure 9 shows variation of the fill fraction as a function of the filling time. As seen from these figure, there is a good agreement between experimental results and numerical predictions obtained for both gravity pouring and counter-gravity casting techniques. Also, the filling time for gravity pouring is ~ 25% higher than that for counter-gravity casting method. One would assume that application of the vacuum impacts on the filling time.

CONCLUSIONS

The results of the CFD simulations of the mold filling dynamics in gravity and counter-gravity lost foam casting are presented. FLOW-3D software package (Flow-Simulations, Inc.) has been used to predict possible locations of fold defects. The results of simulations are compared to those obtained experimentally. A good agreement was found for fill fraction as a function of fill time for both gravity pouring and counter-gravity casting techniques. The filling time for gravity pouring is ~ 25% higher than that for counter-gravity casting method.

ACKNOWLEDGMENTS

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Bakhtiyarov, S. I., Overfelt, R. A., and Alagarsamy, A., 2000, “Advances in Counter Gravity Lost Foam Casting Process”, *AFS Transactions*, Vol. 108, 00-49, pp. 137-145.