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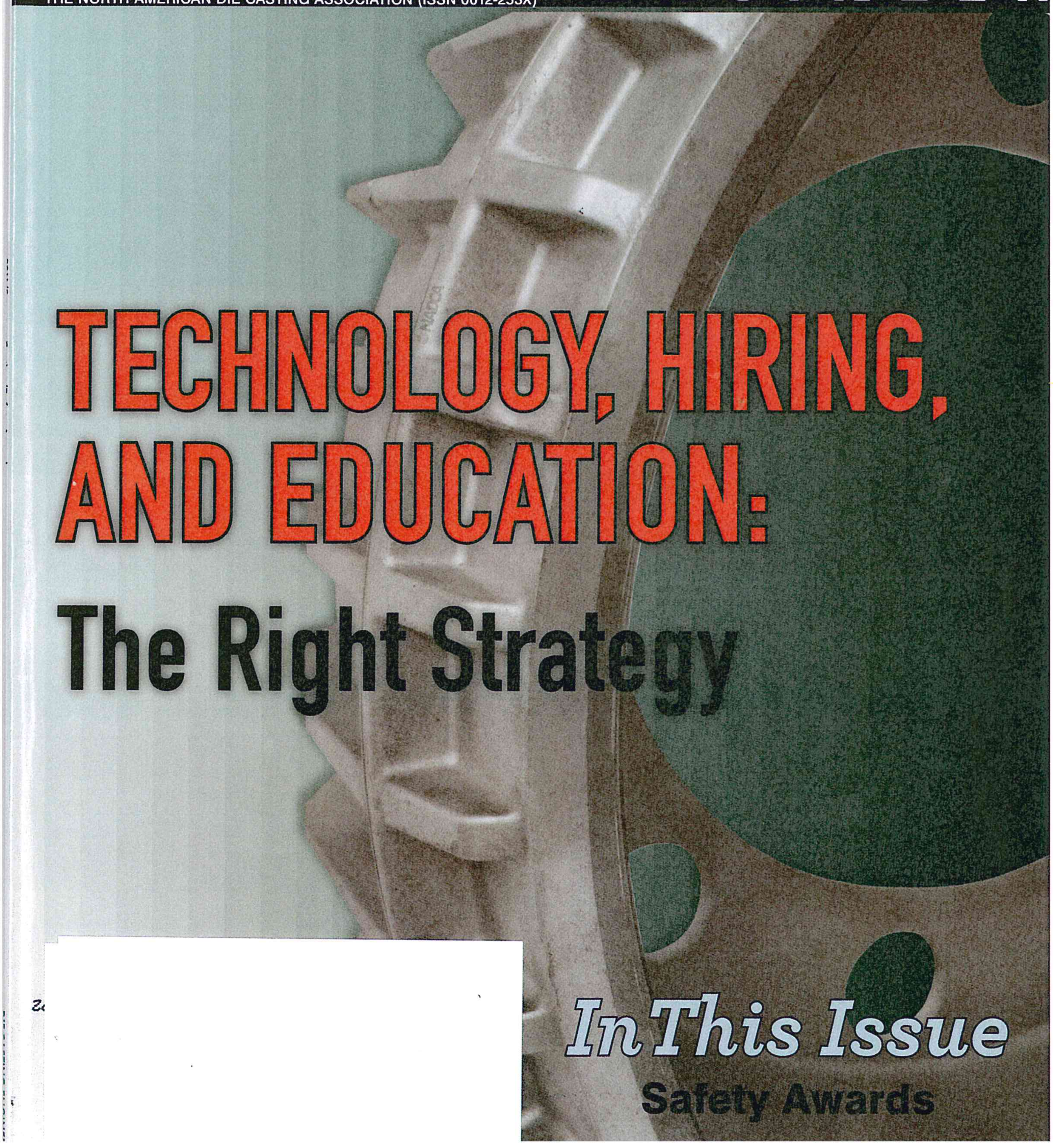

TECHNOLOGY, HIRING, AND EDUCATION:

The Right Strategy

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Safety Awards

Simulation of the Semi-Solid Rheocasting (SSR®) Process in an Automotive Component

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Abstract

Semi-Solid Rheocasting (SSR) is an alternative to traditional casting processes. A new simulation approach will be presented that predicts parameters such as temperature and velocity and visualizes die filling and solidification. Simulation helps identify and eliminate potential defects before they occur. The component used in this study is an automotive cover made of an A380 secondary aluminum alloy. The simulation is carried out with ProCAST* Finite Element (FE) analysis software. The microstructure is characterized by optical and electron microscopy. A model is developed based on experimental data of a homogeneous material in the semi-solid state with thixotropic properties. The microstructure is described with a structural parameter. The simulation results are correlated with physical testing.

Introduction

The semi-solid metal (SSM) casting process offers significant advantages over other casting techniques. Its advantages include non-turbulent filling of the cavity, low shrinkage, lower feedstock starting temperature and longer tool life. Semi-solid casting of aluminum and magnesium components has gained popularity over the last few years for several reasons:

- SSM casting has matured and is competitive in a niche market segment
- With good process control it produces components with consistent mechanical properties
- The process offers lower costs
- Simulation tools make it possible to predict cavity filling and solidification
- A secondary alloy can be used with this technique

In 2002, the Massachusetts Institute of Technology (MIT) and IDRA Casting Machines S.r.l. in the USA developed the SSR process.[1] This process uses a standard High Pressure Die Casting (HPDC) machine with a small accessory.[1,2]

Experimental procedure

SSM technology involves the high-pressure injection of semi-solid slurry obtained from an SSR agitator (Figure 1a). The agitator cools the metal, producing a small solid fraction.[3] The SSM process consists of the following steps:[1]

Step 1: Aluminum is heated to a molten state.

Step 2: A graphite cooling rod is used to agitate and cool the molten metal to a temperature below the liquidus point. The rod is kept in the broth for a short period of time and the agitation speed is kept below 60 rpm. The most critical part of the process is to obtain the first 1% of the non-dendritic solid fraction by volume. The cooling rate must also be carefully controlled during the agitation phase (0.3-3°C•s^{-1}) (Figure 1c).

Step 3: After a short agitation period, the graphite tube is extracted, leaving a slurry with a solid fraction content below 20% that is transferred into the HPDC machine.

The aim of this study was to study the effect of injection conditions on the structural integrity of the secondary alloy A380 obtained by SSR. The composition of the alloy is shown in Table 1.

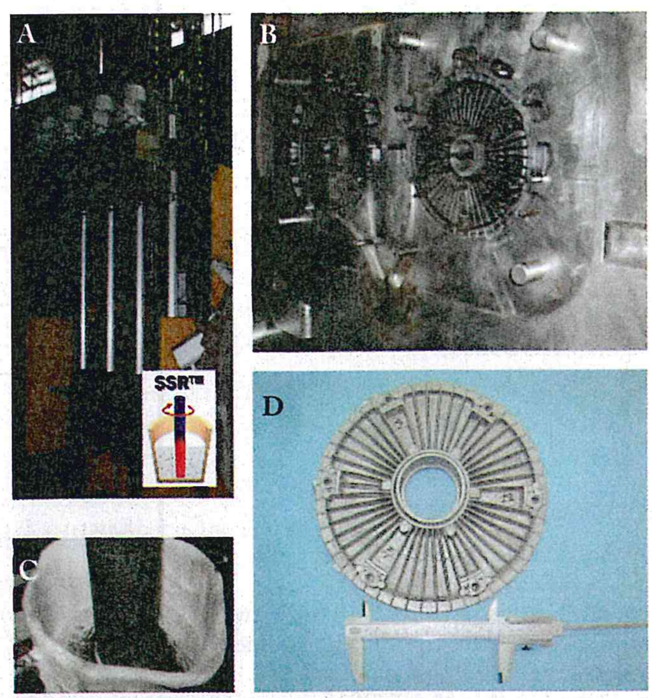

Figure 1 – Photographs of the: a) SSR Station, b) SSR mold, c) graphite agitator, and d) SSR component.

Table 1 – Composition in % weight of the A380 alloy.

Al	Si	Cu	Fe	Mg	Mn
Base	8.7	3.0	0.7	0.15	0.25
Zn	Ti	Ni	Cr	Pb	
0.5	0.05	0.06	0.03	0.08	

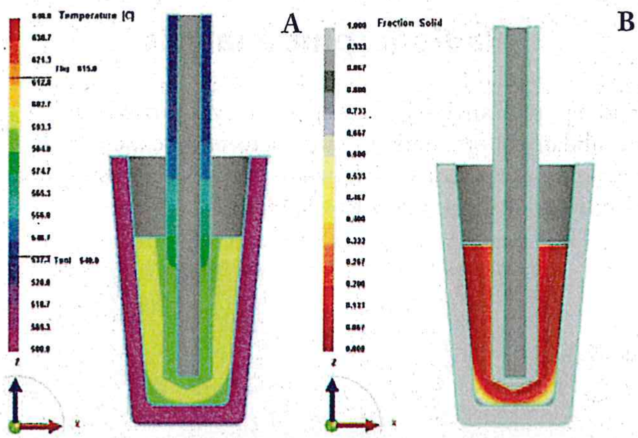

Figure 2 – ProCAST simulation shows a) temperature map of the agitator at 8 seconds of cooling and b) solid fraction map of the agitator at 8 seconds of cooling.

The agitator needs between 8 and 10 seconds to generate a 1% solid fraction in 4 kilograms of A380 alloy (Figure 2).

Semi-solid model used in ProCAST

The injection of metal in the semi-solid state is addressed with two different models. The first model considers the material as a homogeneous fluid with solid and liquid phases. The second model, called the Power Law Cut-Off (PLCO) model, is based on the viscoplastic behavior of an isotropic material independent of pressure and homogeneous deformation.

Equations 1 and 2 describe the flow behavior in thixocasting through a non-Newtonian function of viscosity by incorporating the Navier-Stokes equations[4] in the PLCO model:

$$\mu(\dot{Y},T) = \mu_0(T)\dot{Y}_0^{\,n(T)} \quad \text{for} \quad \dot{Y} \leq \dot{Y}^0$$

$$\mu(\dot{Y},T) = \mu_0(T)\dot{Y}_0^{\,n(T)} \quad \text{for} \quad \dot{Y} \geq \dot{Y}^0$$

Where μ is the non-Newtonian local viscosity, μ_0 the apparent viscosity, $\dot{Y}$ is the shear rate local, $\dot{Y}_0$ Shear rate of cut–off and n(T) the pseudoplasticity index depending on temperature.

In the HPDC process for injection of metal in liquid or semisolid state (SSM), the displacement of the piston is carried out in two steps whose injection speeds are respectively V1 and V2. To study the effect of these speeds, we studied values of V1 and V2 in the range of 0.10 and 0.16 $m \cdot s^{-1}$.

Boundary conditions

The material rheology characterization is based on the PLCO model equations using physical measurements of the local viscosity, the local shear rate and the dependency of these parameters to temperature (Figure 3). These values are used to define the material properties in ProCAST.

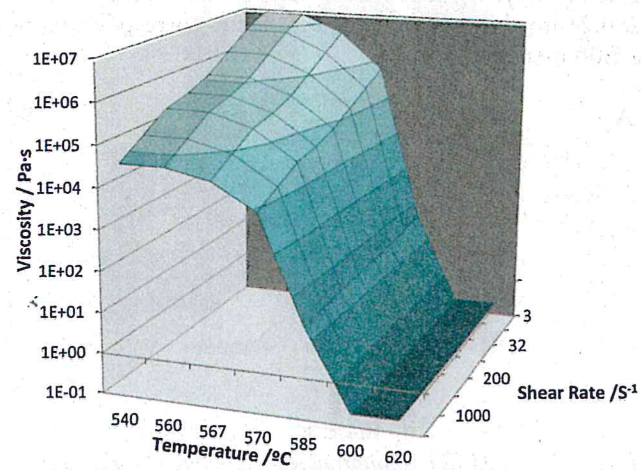

Figure 3 – Viscosity versus temperature and shear rate.

If stretching occurs during the injection of semi-solid slugs into the die, the fluid morphology may change and the shear rate values might be invalid. In the case, the component must be divided into domains with different shear rate values. The automotive cover component is divided into three domains as shown in Figure 4. The domains are roughly divided into the filling channel, overflows and the part itself.

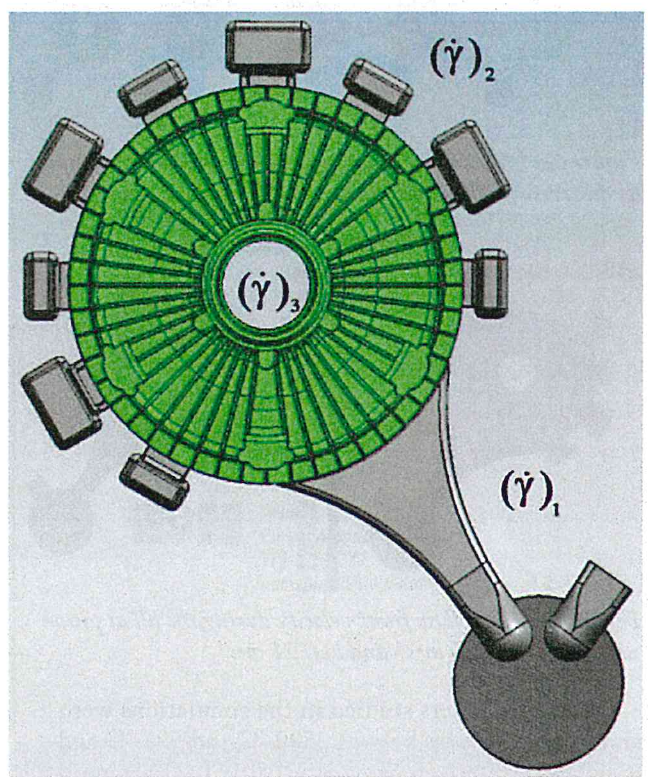

Figure 4 – Component is divided into domains.

Filling velocity effect

In the HPDC process for injection of metal or in a liquid or semisolid state, the displacement of the piston is carried out in two steps whose injection speeds are respectively V1 and V2. The effect of these speeds was studied with values of V1 ranging from 0.1 and 0.16 m•s^{-1} and with V2 equal to V1.

Figure 5a shows the porosity map for a fill at 0.10 m•s^{-1} linear piston speed corresponding to 2.34 m•s^{-1} gate velocity. Figure 5b shows the porosity map for a fill at 0.21 m•s^{-1} linear piston speed piston corresponding to a 5.00 m•s^{-1} gate velocity.

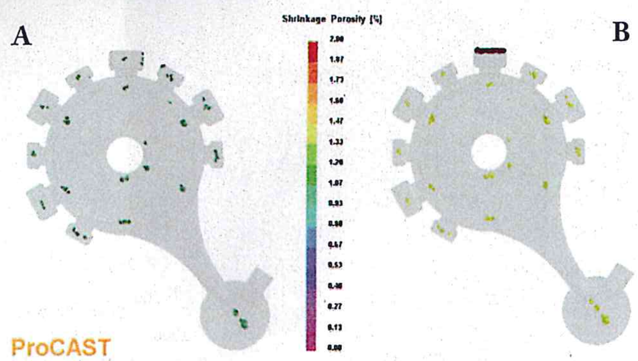

Figure 5 – ProCAST simulation shows a) porosity of the laminar fill and b) porosity of the turbulent fill.

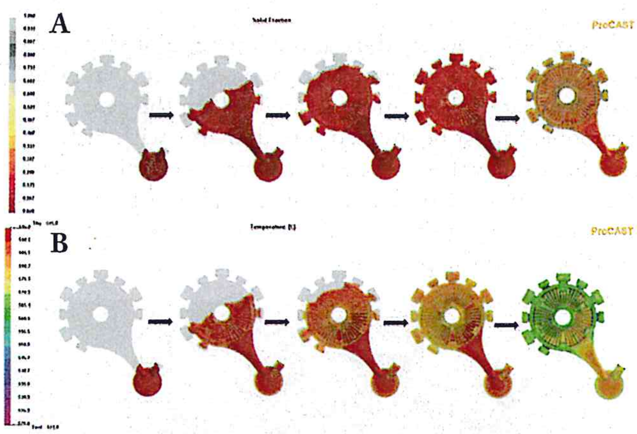

Figure 6 – ProCAST simulation shows a) solid fraction and b) temperature profile maps during the fill, respectively.

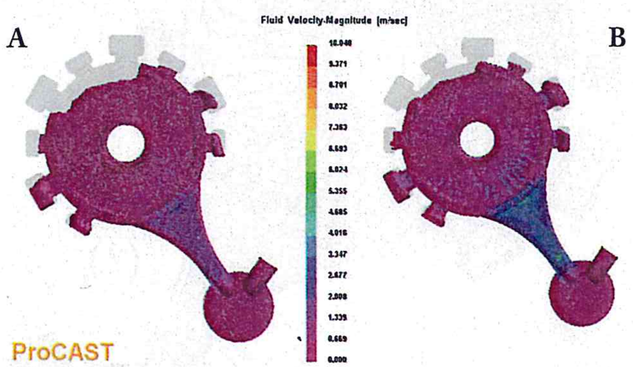

Figure 7 – Metal flow front velocity during the fill at piston velocities of a) 0.10 m•s^{-1} and b) 0.21 m•s^{-1}.

Other parameters studied in the simulations were slurry temperatures between 590 °C and 598 °C and mold temperatures in the area of 305 °C. The simulation was performed with one parameter fixed and while the other was modified. Simulation results showed that if injection is carried out at velocities below the optimal value, solidification occurs prematurely before filling of the die cavity, with corresponding fluctuations in the pressure. This insight made it possible to optimize the injection speed, which in turn reduced the number of defects and porosity in the castings.

Radiographic analysis

Radiographic analyses of components was carried out to validate the simulation. Large defects were identified including gas porosity as shown in Figure 8. Porosity was eliminated by injecting with a laminar fill.[5]

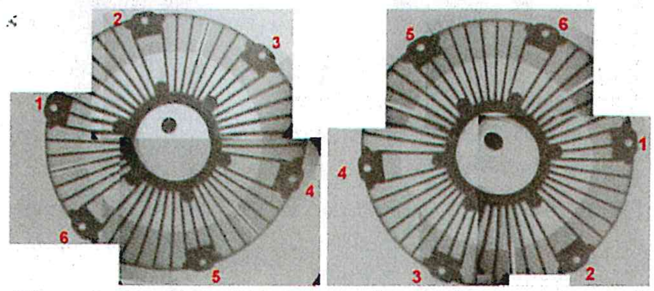

Figure 8 – Radiographic analysis of two different components.[5]

Metallographic analysis

The microstructure of as-cast A380 aluminum alloy (Figure 9) consists of primary grains of the α-phase solid. The α-phase is surrounded by a very thin eutectic layer in which intermetallic compounds can be detected. Energy dispersive spectroscopy (EDS) analysis revealed Al(Si,Fe,Mn,Cu), Al(Si,Fe,Mn,Cu,Cr), α-AlFeSi, Mg_2Si and $CuAl_2$. In contrast to the thixocasting process, eutectic microconstituents occluded in the α-grains were not observed.

The eutectic silicon phase seems to be the most important crack initiator in AISi7Cu3Fe0.2 alloy. However, previous studies have shown that when iron content exceeds 0.6%, fracture tends to begin in the iron phases more than the silicon.[6]

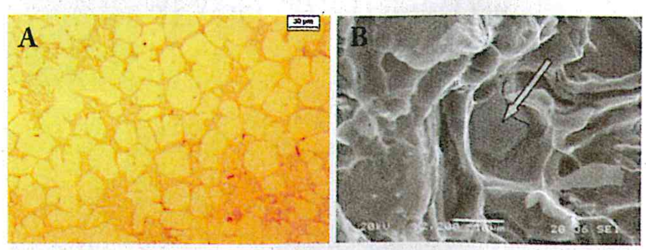

Figure 9 – a) Micrograph of A380 SSR as-cast and b) scanning electron microscope (SEM) micrograph of EDS analysis that detected the Al(Si,Fe,Mn,Cu,Cr) intermetallic compound.

Conclusions

The PLCO model used in the ProCAST casting simulation program from ESI Group (www.esi-group.com) is a useful tool to predict mold filling behavior with A380 slugs in semisolid state.

For this shot casting shot size with the SSR process, agitation of less than 8 seconds doesn't generate globular alpha while agitation of greater than 12 seconds prevents successful injection.

A small increase of about 10 °C in liquid temperature doesn't increase the porosity that is concentrated in the larger areas of the component and near the gates.

The simulation showed the best results were achieved at 595 °C slurry temperature, 305 °C mold temperature and 2.34 ms^{-1} gate velocity (v_{piston} = 0.10 ms^{-1}). This injection velocity is far lower than the standard HPDC process.

Simulation shows that high speed injection increases solidification porosity or microporosity but the value remains below 1%. Radiographic analysis confirmed these results.

Acknowledgement

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*ProCAST is a leading casting simulation software solution from ESI Group. For more information about ProCAST, please visit www.esi-group.com/casting.

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