Abstract

Low-pressure die casting (LPDC) process is a near net shape casting method. Due to the high precision and high efficiency requirements as well as its capacity for high quality wheels at low cost, LPDC is considered as the dominant process for the production of aluminum alloy wheels. The molten aluminum flows through the running system into the die cavity and then fills the die. During the cavity filling, interactive heat transfer occurs between molten metal and die surface. Combination of die temperature, fluidity of the molten metal, geometrical complexity of the parts, and cooling rate during die casting affect the integrity of a cast component. Casting of relatively hot molten metal into the mould without sufficient surface isolation by a suitable lubricating medium causes great straining of the surface layers of the casting die material. Various refractory based die coatings are used to improve thermal stability of the die and their thermal barrier effect determine the die casting performance and process efficiency.

Thermal barrier coatings (TBCs) are used to reduce the operating temperature of the surface and to extend the durability. Zirconia (ZrO₂) stabilized with magnesia (MgO) or yttria (Y₂O₃) coatings have been used in gas turbine parts as thermal barriers for several years. The TBC system applied to hot part surface usually consist of a ceramic (stabilized zirconia) top coat (TC: 250-1000 μm) that reduces the temperature; a metallic (NiCr/ NiAl) bond coat (BC: 50-150 μm) to enhance the bonding between the top coat and the underlying substrate. ZrO₂ 8wt% Y₂O₃ is extensively used as the TBC material because of its low thermal conductivity and excellent mechanical properties. When the relatively porous thermal barrier coating (with 10 vol% porosity) tested at 1316 °C for 20hr, the heat transfer coefficient value has been measured as 1.0 W/mK [7]. Plasma or flame sprayed magnesia (%20-24MgO) stabilized with zirconia coatings consist of different range (%10-50) porous top coating. MgO-ZrO₂ top coatings are economically cheaper and have a higher thermal expansion characteristics. They are good candidate for die casting die protection applications. With the higher porous nature and thickness of the coating greatly can be reduced the thermal conductivity. The porosity ratio and thickness of top coating could be controlled with thermal spray process parameters and feedstock material properties [6-10]. Numerical models are considerably useful in analyzing the effect of microstructure on thermal conductivity and for supporting microstructure designs that can decrease thermal conductivity and exist in theory. The investigation of the effects of pore geometry on conductive within the TBCs over a range of temperatures has shown that the main factor in controlling the conductivity was the inter-splat bridges and porosity morphology. The temperature of the coating decreased as the porosity increased in the microstructure. It was observed that the pores decreased the heat transfer along the heat flow direction. The shape and orientation direction of the pores in the TBC affected the thermal conductivity [10].

Since it is difficult to make estimation for the casting process details in advance, casting process...
simulation software is widely used in industrial applications to determine the process parameters and to predict possible complications in process. Therefore, in this study the effect and performance of thermal spray ZrO₂-MgO/ NiCr based thermal barrier coating is investigated on the LPDC wheel casting process comparatively with traditional die coating and uncoated wheel die using MAGMASOFT casting simulation software.

2. Materials and Method

Al alloy passenger car wheels are generally manufactured by Low Pressure Die Casting method. In the method, molten Al alloy held in air tight holding furnace under the LPDC device is transferred to the metallic mold. The thermal isolation of die material is quite important due to the thermal cycle during the casting process. In the industry generally ceramic based conventional water suspension coatings are used. On the other hand, the thermal and mechanical advantages of ceramic based thermal barrier coatings are obvious over conventional coatings. Therefore this study investigates the effect of coating and consequently heat transfer between the cast and parts of mold. In the study, MAGMASOFT V5.2 casting simulation software was used to model the LPDC process of an Al alloy wheel. The alloy wheel was made of A356 alloy and filling and solidification and thermomechanical material parameters are already defined in the library of MAGMASOFT. The particular model consisted of a wheel, a bottom core, an upper core, and four side cores, plates where cores attached to LPDC system, riser tube, and filter.

Governing equations of MAGMASOFT casting software are continuity equation, Navier–Stoke’s equation, energy equation and volume of fluid (VoF) method for the movement during the filling of die. MAGMASOFT uses the finite volume method to convert differential equations into algebraic ones and solve them. The whole assembly was discretized with total 8.000.000 cubic volume elements.

In the study, four different simulation setups were prepared considering coating on die material. The corresponding heat transfer coefficients were given in Table 1 for different temperature regimes. Non-coated and conventional die coating heat transfer coefficients were obtained from MAGMASOFT database, and the heat transfer coefficients of thermal spray coated dies were determined considering coating thickness and porosity according to literature survey. The effective thermal conductivities of coatings with various porosities for 800 °C determined by means of a CFD method, the Maxwell-Eucken and Effective Medium Theory (EMT) model. [8-10].

A number of 5 cycles were taken after the start-up of casting process to ensure a steady state temperature profile in the die and to demonstrate the real process conditions better.

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Sim-1 Non-Coated</th>
<th>Sim-2 Convent. Die Coating</th>
<th>Sim-3 TBC t:450 μm P:25%</th>
<th>Sim-4 TBC t:850 μm P: 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-542</td>
<td>1000</td>
<td>400</td>
<td>800</td>
<td>500</td>
</tr>
<tr>
<td>542-613</td>
<td>2700</td>
<td>620</td>
<td>1000</td>
<td>750</td>
</tr>
</tbody>
</table>

TBC: Top coat (TC): MSZ; ZrO2-MgO + Bond Coat (BC): NiCr/ TC+BC=TBC (Total Thickness; t, P:Porosity)

3. Results and Discussion

In Figure 1, temperature distribution of simulations can be seen comparatively at 300 seconds of filling simulation. As can be seen, the highest temperature in non-coated mold was obtained in hub region where the molten metal enters into the mold cavity and gradually decreases radially through the spoke-rim intersection of the mold. Comparatively for Sim-2, conventional coatings can provide a good thermal isolation due to their ceramic base and temperature levels were dropped to some lower values through the mold section. Due to relatively higher heat transfer coefficients of thermal barriers modeled in Sim-3 and Sim-4, temperature values across the section is a bit higher than conventional coating but again lower than non-coated mold material modeled in Sim-1.
Figure 1. Comparison of temperature distribution of simulation results (a) Sim-1, (b) Sim-2, (c) Sim-3, (d) Sim-4.

In Figure 2, temperature histories for different simulations and different virtual thermocouple regions can be seen comparatively. As can be seen for all regions, temperature values were between non-coated and conventional coating for thermal spray coated Sim-3.

In Figure 3, temperature histories of Sim – 2 and Sim – 4 can be seen comparatively to obtain the performance of second thermal spray coating.
Figure 3. Temperature histories of (a) Hub, (b) Spoke, and (c) Spoke-Rim intersection regions for Sim – 2 and Sim – 3.

4. Conclusion

The effect of thermal isolation on LPDC wheel process was investigated numerically. In the study performance of two different thermal barriers was compared with non-coated mold material and a conventional ceramic based coating material. Results showed that, TBC using in both of the bottom and the top mold can reduce the hot spots at rim/spoke junctions. This led to the decrease of the temperature to a certain extent and satisfies the practical requirement in production. Uniform temperatures gradients are existed in both metal and mold, the junction between the two surfaces creates a temperature drop.

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References


