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USE OF NUMERICAL SIMULATION IN THE PRODUCTION OF POROUS-METAL CASTINGS

UPORABA NUMERIČNE SIMULACIJE V PROIZVODNJI POROZNIH KOVINSKIH ULITKOV

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The article describes the design and optimization of the foundry production of porous metal. The formation of porous metal by infiltrating liquid metal into the mould cavity appears to be the fastest and most economical way. However, it is not possible to do it without proper production parameters. For this reason, a 3D model of a particular casting is first created in the Rhinoceros 4.0 software and then the entire production process is designed and optimized using the numerical simulation in the MAGMASOFT® 5.4 software. To create cavities in the casting, the use of sand cores is considered and the used unit bentonite mixture (UBM) becomes the mould material. With the simulations of pouring and solidification of the casting, the right conditions for the real production can be defined precisely; the time and financial costs connected with the production of non-conforming pieces can be saved. Thus, the aim is to ensure the production of sound castings that will find their use in the field of energy, specifically as heat exchangers.

Keywords: porous metal, simulation software, casting, heat exchanger

V članku avtorji opisujejo dizajn in optimizacijo ulivanja poroznih kovinskih ulitkov. Ugotavljajo, da je formiranje porozne kovine s postopkom infiltracije raztaljene kovine v votlino livarskega modela najhitrejši in najbolj ekonomičen način. Toda tudi v tem primeru tega postopka ni možno izvajati brez ustreznih proizvodnih parametrov. Zato so avtorji najprej kreirali 3D model izbranega ulitka s programsko opremo Rhinoceros 4.0 in nato s programom MAGMASOFT® 5.4 izvedli numerično simulacijo dizajna in optimizacije celotnega proizvodnega procesa. Za izdelavo livarskega modela so uporabili peščena jedra in betonitno mešanico (UBM). S simulacijo polnjenja modela z raztaljeno kovino in strjevanja ulitka pri optimalnih pogojih so tako v realni proizvodnji lahko natančno določili čas in stroške, ter s tem prihranke, pri izdelavi ulitkov različnih zahtevnih oblik. Avtorji so tako omogočili proizvodnjo kvalitetnih ulitkov, uporabnih na energetskem področju, predvsem za izmenjevalnike toplote.

Ključne besede: porozna kovina, programska oprema za simulacijo, litje, toplotni izmenjevalnik

1 INTRODUCTION

A porous metal has intentionally created cavities/ pores in its structure. According to the arrangement of internal cavities, such materials can be divided into regular and irregular ones. The internal structure of porous metals differs depending on the technology used. A porous metal can be produced in various ways, but the production is economically demanding; therefore, it is good to have a production that uses casting technologies where the lowest costs are expected. As a result, we can combine the technologies of forming cavities with the use of sand cores. Depending on the size, openness and amount of pores, different behaviours are observed in the field of thermal conductivity. Open pores in a material increase its thermal conductivity. This can be used for the design of heat exchangers. The principle is to let a fluid or gas flow through the open pores of a material, which will cool down or heat up the porous metal. To increase the economy of the casting production of heat exchangers, it is suitable to use the MAGMASOFT® 5.4 – Autonomous Engineering simulation program that is a very mature tool for the simulation of all the casting operations from the beginning of pouring to the end of the cooling process. By correctly setting the simulation program and boundary conditions, and establishing the appropriate goals, critical points of the casting can be found in advance and unnecessary elements of the gating system that burden the foundry with additional processing costs, can be removed.[1–3]

2 EXPERIMENTAL PART

Several variants of the heat exchanger in the environment of the ANSYS CFX simulation program was first analysed. Based on the calculations of the heat-transfer simulations, the geometry with ball cores seemed to be more efficient. A model of a casting and cores was first created as a drawing and then it was modelled with the Rhinoceros 4.0 program (**Figures 1** and **2**) and inserted into the MAGMASOFT® 5.4 program. After the production, the sand cores were put in pairs next to each other and provided with prints. The material of the mould used for casting the heat exchanger consisted of the unit bentonite mixture (UBM). The casting weight

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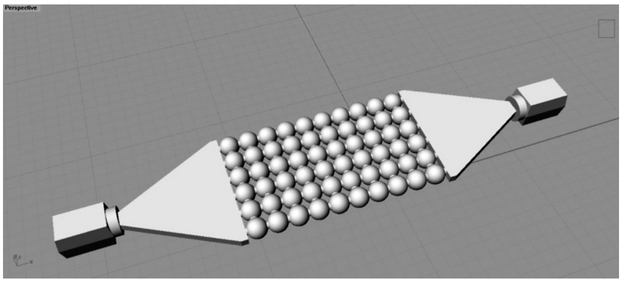

Figure 1: 3D model of a sand core

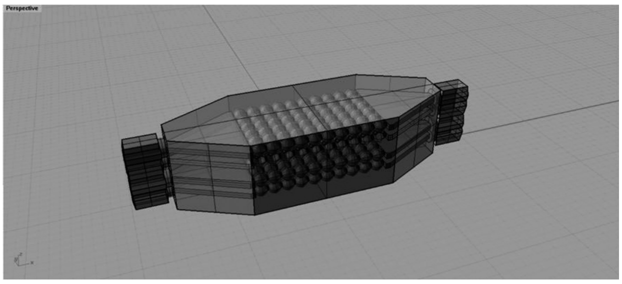

Figure 2: 3D model of a casting with cores

was 4.72 kg and the volume was 1784.28 cm^3. The used material was the AlSi10Mg alloy.[4,5]

The next step was the creation of several different variants of the gating system and their comparison. Subsequently, the suitable candidate for the design-of-experiments (DoE) analysis was chosen. The porosity of the casting, the optimum casting temperature of the metal, the subsequent metal temperature in the casting before the material solidification, the flow rate of the metal in ingates and in the casting, the microporosity, the ability of feeding the used risers, the size and shape of ingates and the casting time were the monitored parameters.[6]

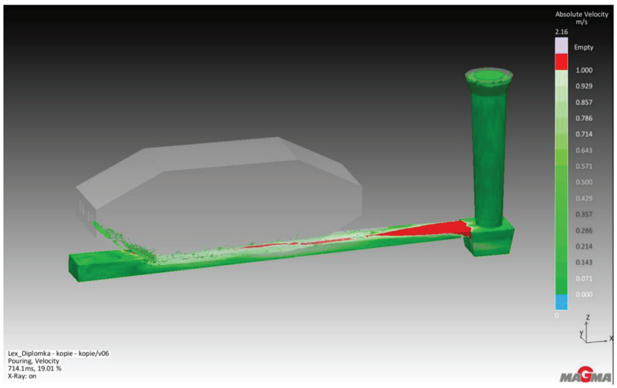

Figure 3: Filling rates

3 RESULTS

From the initial simulations that lasted for nearly 120 h, the variant from **Figure 3** was chosen as the suitable candidate for the DoE analysis because it allowed low filling rates. Optimization was created based on the variables that were included in the geometry, namely the ingate width, the angle of the end over-hanging from the vertical wall up to a 30° incline, the

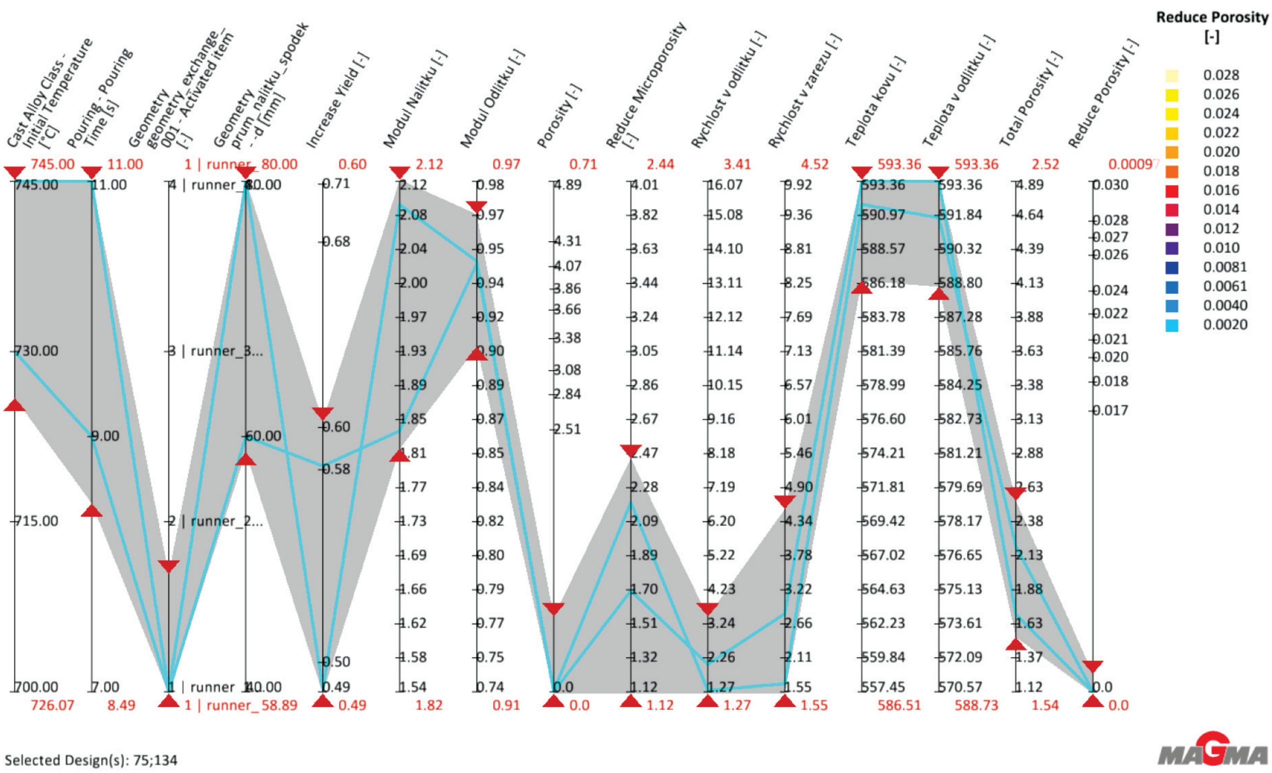

Figure 4: Filtered results of the DoE analysis

riser diameter that was set to the values of the diameter of the bottom side of (40, 60 and 80) mm and the casting temperature. Altogether 144 pieces of the variables were examined. The calculation time of the DoE analysis subsequently reached 192 h. Of course, the calculation time could be shortened significantly using a more powerful station (PC). The overall results of the analysis were recorded in a chart and filtered results of two suitable designs are shown in **Figure 4**. In the top part of the chart, the criteria according to which the achieved results were filtered out are described.

The following criteria were used when choosing suitable candidates: reduction of porosity, minimum temperature in the casting, minimum temperature of the metal, lower rate in ingates, lower rate in the casting, reduction of microporosity, higher feeding ability of the riser, and usage of liquid metal. A longer filling time was chosen to comply with the lower rates in ingates. The riser dimension was changed in terms of its diameter, not height, due to testing the variants with a sufficient feeding ability. At the same time, it is evident from **Figure 4** that the candidates satisfying the specified values are versions 75 and 134.

4 DISCUSSION

Versions 75 and 134 were subsequently added for comparison. Filling rates of up to 0.5 m/s, which is an acceptable border, were recorded for the casting. There was no damage of the cores and the filling was fast enough. Version 134 on the figure right shows lower rates than the more turbulent version 75 on the left. When choosing between versions 75 and 134, it was decided in favour of version 134. Although version 75 showed a better thermal node and a smaller drop in the temperature, the riser was uneconomical. Further, version 134 showed a more continuous filling of the entire cavity. With regard to the drop in the temperature of the 134 design, two additional simulations were made, in which the existing casting temperature compared to the newly modified one was evaluated. The initial casting temperature was 745 °C and there were too many temperature drops in narrow intercore areas. The temperature of the newly simulated sample was set to 755 °C. Microporosity was also studied in both of the above-mentioned simulations. The results were positive, including a very low value of only 4 % of the total volume, spread across the casting body.

5 CONCLUSIONS

The variant with serial number 134, which was simulated at a casting temperature of 745 °C, was selected as the winning design of the casting. Then the casting temperature was changed to 755 °C and the variant was analysed again and compared with the previous state. As expected, the increased casting temperature had a positive influence on the fluidity in the intercore areas. Therefore, the casting temperature of 755 °C was determined as the minimum temperature for a successful casting of the tested sample of the heat exchanger. The riser size was sufficient for eliminating the thermal node and compensating for the material loss. At the same time, the gating system allowed faster casting than the simulation, lasting 11 s. Common conditions used in a foundry when the casting rate is not strictly observed were taken into consideration and, therefore, the simulation was calculated with a reserve. The acceleration of the casting time without a negative influence on the increase in the flow rate of the metal in the mould cavity can be up to 15 %.

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