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SIMULATIONS OF THE SHRINKAGE POROSITY OF Al-Si-Cu AUTOMOTIVE COMPONENTS

MODELIRANJE KRČILNE POROZNOSTI Al-Si-Cu AVTOMOBILSKIH ULITKOV

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The 3D shoot-sleeve and shrinkage-porosity simulations of a high-pressure die-casting (HPDC) process are presented using the ProCast casting-simulation software. The porosity was studied during the casting and solidification of aluminium-silicon-copper alloy components in an H13 steel die. Excellent agreement between the simulated and experimental results was observed.

Keywords: high-pressure die casting, aluminium-silicon-copper alloy, shrinkage porosity, ProCast software

V tem prispevku je prikazano 3D-modeliranje pomika bata in krčilna poroznost procesa visokotlačnega litja (HPDC) z uporabo programskega paketa ProCast. Študija poroznosti je prikazana na aluminij-silicij-bakrovih ulitkih, litih v orodje iz jekla H13. Analiza je pokazala zelo dobro ujemanje med modeliranimi in eksperimentalno ugotovljenimi rezultati.

Ključne besede: visokotlačno litje, aluminij-silicij-bakrova zlitina, krčilna poroznost, ProCast

1 INTRODUCTION

To manufacture a large variety of products with high dimensional accuracy using the process of high-pressure die casting (HPDC) the fast and economical production of aluminium automotive components has been developed.[1] In the past two decades the rapid development of numerical simulation methodology and the solidification simulation of castings have been introduced as an effective tool for modeling the casting process and improving the quality of castings.[2,3] The use of simulation software saves time and reduces the costs of the casting-system design and of the materials used.

The physical, mechanical and esthetic properties directly depend on the metallurgical operating conditions during casting. The combination of the mechanical properties of the die-cast product, such as the die temperature, the gate metal velocity, the applied casting pressure, the cooling rate during die casting, the geometrical complexity of the parts and the mold-filling capacity, all affect the integrity of the cast components. If these parameters are not controlled properly, various defects in the finished component are to be expected. The applied casting pressure is crucial during the solidification of high-integrity parts. The effects of process variables on the quality of cast components with in-cavity pressure sensors, delay time and casting velocity were examined by Dargusch in 2006. He found that the porosity decreased with increasing intensification pressure and increased with a higher casting velocity.[1,4]

The porosity of castings can be examined with destructive testing, with visual observation after machining and non-destructing testing, like X-ray microscopy and image-processing technology, which can provide more detailed information about the pores. It is also observed that the chemical composition of the alloy affects the porosity of the cast components, the grain refinement and the modification.[5,6] Now it is commonly accepted that the shrinkage and the gas are the two major causes of porosity. The shrinkage porosity is associated with the "hot spots" in the casting. The gas porosity is caused by entrapped air in the injection system and the cavity, the gas generated from burned lubricants, the water in the cavity and hydrogen. The entrapped air is the unwanted product of the high velocity of the alloy caused by the turbulent flow during the injection process.

The paper describes a simulation of the HPDC of an Al-Si9Cu3 casting in an H13 steel die and the comparison between the simulated and the experimental porosity.

2 EXPERIMENTAL

2.1 Material and casting system

The alloy used for the die casting was an aluminium-silicon-copper alloy (**Table 1**). The alloy is less prone to shrinkage and internal shrinkage cavities and has a very good castability. The ALSI H13 chromium hot-work tool steel was used for the die. This steel has a higher resistance to the heat cracking and die wear caused by the thermal shock associated with the

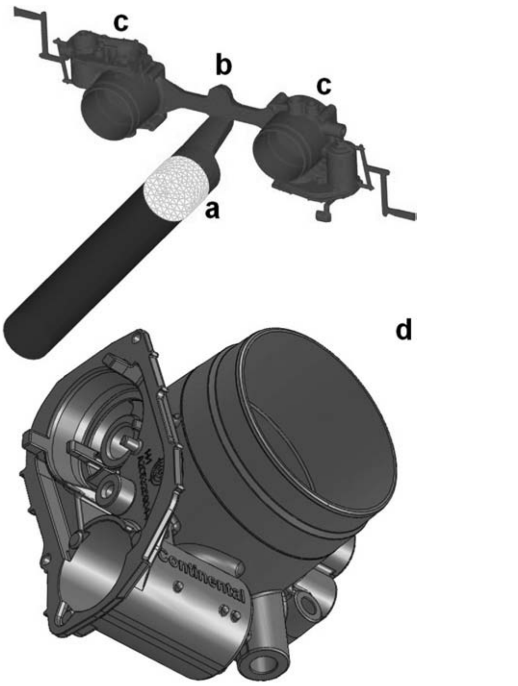

Figure 1: Casting system: a) shot sleeve with plunger, b) gates and runner system, c) the two cavities left and right and d) the casting component

Slika 1: Ulivni sistem: a) livna komora z batom, b) ulivni in dovodni kanal, c) dve livni votlini leva in desna in d) ulitek

die-casting process.[7] The casting system with a shot sleeve and a plunger are presented in **Figure 1a**. The gates and runner system with two cavities are presented in **Figures 1b** and **1c**. The final product is an automotive component (**Figure 1d**).

Table 1: Chemical composition in mass fractions of the Al-Si9Cu3 alloy, *w*/%

Tabela 1: Kemijska sestava Al-Si9Cu3 zlitine v masnih deležih, *w*/%

Si	Cu	Fe	Mn	Mg	Zn	Ni	Cr
10.38	2.73	0.82	0.25	0.34	0.82	0.04	0.04

2.2 HPDC process

The casting process can be divided into four phases: the pre-filling, the shot, the final pressure phase and the ejection phase. In the pre-filling phase, the molten metal is injected by a plunger, which forces the metal with a low velocity through a horizontally mounted cylindrical shot sleeve up to the gate. Usually, the shot sleeve is partially filled with molten metal, the amount of which depends on the cast component volume. The remaining volume is empty. Previous research work has shown that the fluid flow and the amount of empty space are affected by the plunger motion, the shot-sleeve dimensions and the amount of metal in the sleeve.[8] In the short-shot phase the plunger is accelerated to high velocity and so any venting of the die cavity is practically impossible. In the final pressure phase, solidification of the casting is completed and in the ejection phase, the moulded part is removed, the die halves are sprayed and positioned back to repeat the cycle.

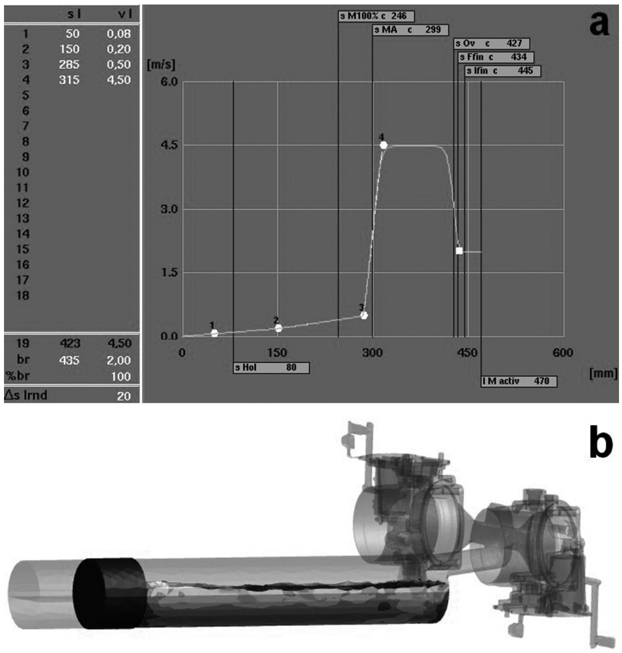

Figure 2: a) Shot profile with four different plunger speeds and b) volume fraction picture of the alloy and the empty space in the shot sleeve

Slika 2: a) Diagram pomika bata s štirimi različnimi hitrostmi in b) slika volumenskega deleža zlitine in atmosfere v livni komori

The industrial HPDC process for casting an automotive component starts with a plunger that has four

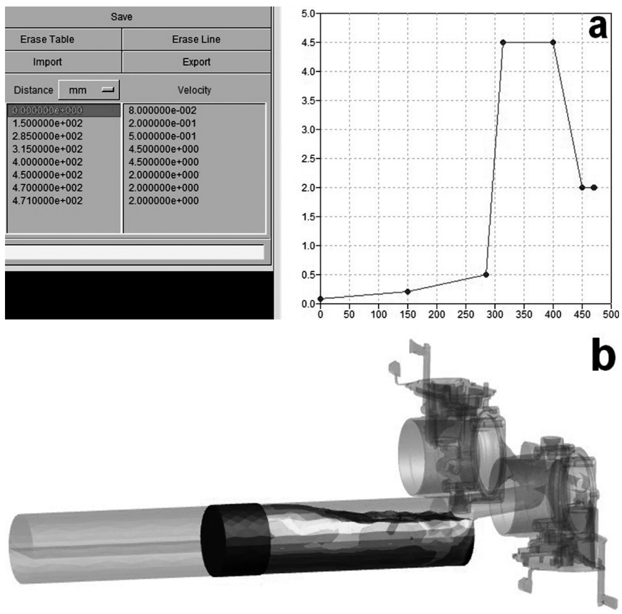

Figure 3: a) Shot profile with three different plunger speeds and b) volume fraction picture of the alloy and the empty space in the shot sleeve

Slika 3: a) Diagram pomika bata s tremi različnimi hitrostmi in b) slika volumenskega deleža zlitine in atmosfere v livni komori

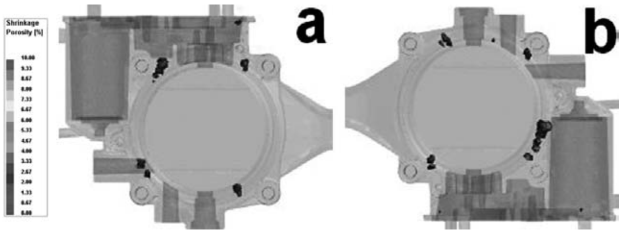

Figure 4: Shrinkage porosity simulation of: a) left and b) right castings
Slika 4: Simulacija krčilne poroznosti a) na levem in b) desnem ulitku

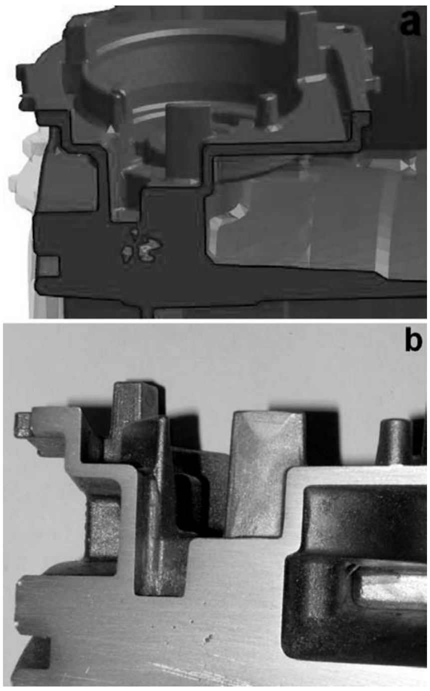

Figure 5: Shrinkage porosity in left casting at spot 1: a) simulation, b) cut section
Slika 5: Krčilna poroznost v levem ulitku na mestu 1: a) modeliranje, b) prerez

different speeds, as shown on the shot profile in **Figure 2a**. The volume fraction in **Figure 2b** shows that there was no wave and no air entrapment.

3 RESULTS AND DISCUSSION

3.1 The shot-sleeve simulation

The same industrial HPDC process was then simulated with the FEM-based software called ProCast. The movement of the plunger was simulated using three different plunger speeds. The simulation is shown on the shot profile in **Figure 3a**. The volume fraction in **Figure 3b** shows no wave and no air entrapment.

The set-up time was minimized, the plunger speed increased and the industrial HPDC process was shortened by 0.48 s.

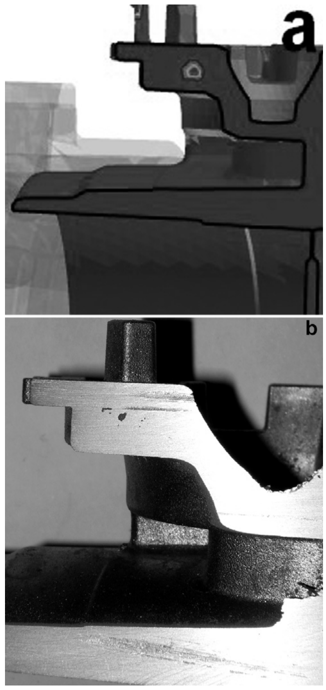

Figure 6: Shrinkage porosity in left casting at spot 3: a) simulation, b) cut section
Slika 6: Krčilna poroznost v levem ulitku na mestu 3: a) modeliranje, b) prerez

3.2 The shrinkage-porosity simulations

The shot-sleeve simulation results were used as the boundary conditions for the cavity-filling simulations and the shrinkage-porosity simulations, as the basic study in this paper was the shrinkage porosity. **Figure 4** shows the simulated shrinkage porosity "red spots" in the left and right castings were the porosity spots are marked with numbers. After nine cycles of casting constant conditions in the die were established and after ten cycles in the left-side casting two red spots of simulated shrinkage porosity were examined (**Figures 5** and **6**) and in the left casting (**Figures 5b** and **6b**) a good agreement with the simulated results of shrinkage porosity was found (**Figures 4, 5a** and **6a**).

4 CONCLUSIONS

In the present work the porosity of automotive components was analyzed with ProCast, FEM-based software. The most important conclusions that can be drawn are:

- The shot-sleeve simulation gives valuable information for the final quality of the components by minimizing the volume fraction of the empty space during the first stage of the HPDC process. The volume fraction shows no wave and no air entrapment.
- The shot-sleeve simulation gives savings in cycle time by minimizing the set-up time during the shot

stage of the HPDC process. The shot stage of the HPDC process set-up time was shortened by 0.48 s.

- The shot-sleeve simulation also gives information about the shrinkage-porosity location in castings, called "red spots". The shrinkage porosity on the sections of spots 1 and 3 in the left-side casting is in good agreement with the simulated results.

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