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MOLD FILLING IMPROVEMENT BY COMPUTER SIMULATION AND PARAMETER VARIATION

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ABSTRACT
Porosity is one of the major defects in aluminium castings. So the tendency to resolve it's formation in the casting process is dictated by important fact of its appearance on the machined surface of the final product. In this paper a piston casting was observed which is representative of complex shape castings. Observed part is a real casting produced in foundry with a considerable scrap loss due to porosity. During production there are some solidification problems, due to the poor feeding of the thinnest part of the piston wall, where the copper chills are applied. The idea is to investigate the influence of variety casting parameters and casting design by computer simulation and create rules for process improvement.

KEYWORDS
Porosity, casting, piston, computer simulation

1. INTRODUCTIONS

The increasing number of applications and of products is the best proof of the success of aluminium alloys foundry industry. This is probably one of the most dynamic fields inside manufacturing and engineering. The well-known advantages associated to the use of Aluminium alloys are: light weight, good mechanical behaviour, good corrosion resistance, etc [1]. Vertical permanent mold gravity casting is a common method for aluminium alloys casting because it is cost effective production method, especially in high volume applications. On the other hand there is a formation of porosity in aluminium alloys which is well known as a problem relating to it's good thermal conductivity, long freezing range and large decrease of hydrogen solubility from liquid state to solid state [6]. So reducing the appearance of porosity defects is very complex operation which has to take into consideration many different fields of casting process.

Porosity is divided in three groups, which are: solidification shrinkage, gas precipitation during solidification and gas entrainment. Shrinkage porosity forms when there is an insufficient feeding while the casting solidifies and gas precipitation is caused by a residual gas in supersaturated initial melt. The only gas that dissolves in aluminium melt is hydrogen so the only pores that could form by gas precipitation are hydrogen gas pores. Gas entrainment porosity is produced by a surface turbulence during the filling of the cavity by molten metal. To eliminate gas entrainment defects it is essential to assure smooth filling by well designed gating system, and provide enough liquid metal to do critical areas during solidification [3].

In recent years, the aluminium foundry industry has been using a general set of practices for gating of permanent mold aluminium castings. These principles were developed using historical "lessons learned" in an evolutionary process [5]. Few of these principles have been either confirmed or refuted through experimentation and simulation. Because of this lack of experimentation, few improvements have been made to the current gating practices.

Furthermore, many gating systems are developed using these principles with little understanding as to what happens in the mold during filling. A lack of true gating understanding causes many foundries to produce poor quality castings. Defects may arise in the casting that are direct results of poor gating practices implemented by blindly following gating guidelines [5]. Laying out casting technology in a past decade has become computer aided which offers faster and more accurate designs of the casting process than traditional trial and error methods. Trial and error on the foundry floor has been replaced by trial and error on the computer. Although the results of the computer simulations are not exact they give enough information about relations of parameters in the process of filling and solidification of the casting. Redesigning the casting, and changing of parameters is repeated until the desired result is obtained [3].

The goal of this paper was to understand the behaviour of the process, reveal parameters that affect defect formation and consider a possibility to lower the casting temperature and in that term to avoid such oxidation and reduce production cost.

2. METHODOLOGY

Piston observed in this work is made of Al-Si alloy, also called as piston alloy. On the figure1 it is shown the configuration of the casting with all of it elements, runners, ingates and feeders. As it can be seen two pistons are casted in one cycle, attached to vertical downsprue. This piston is a real work piece produced in foundry so this observation, like the earlier one [4], has a big practical importance. There are many different parameters that could affect the formation of porosity in this casting and this fact led us through variations presented in this paper. Earlier investigation [4] has proved that there are solidification problems, due to the poor feeding of the thinnest part of the piston wall, where the copper chills were applied. Another origin of porosity could be the turbulence of the melt and the effect of gas entrainment. This paper will present how the variety of ingates and lower casting temperatures can affect the filling behaviour and later the solidification of the casting. Variations on feeder configuration were also made to examine it's role in solidification process of the critical area.

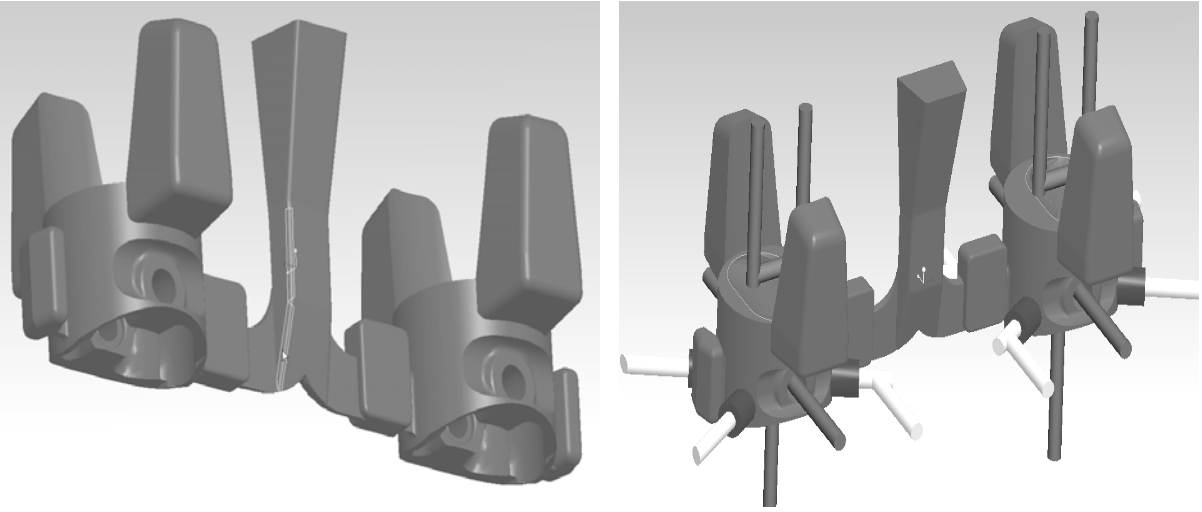

Figure 1. Casting model (left), casting model with cooling systems (right)

Computer simulation of the casting process was carried out on finite elements software. Thermophisical parameters needed for calculations were measured in production or were taken from specification of cast material. Like in the production process four copper chills were applied at every piston and water channels were embedded in the mould, figure1. Considering this symmetrical problem simulation was performed with a half model which is a regular representative of the casting. Three simulations were performed with lower casting temperature and different ingate dimensions figure2.

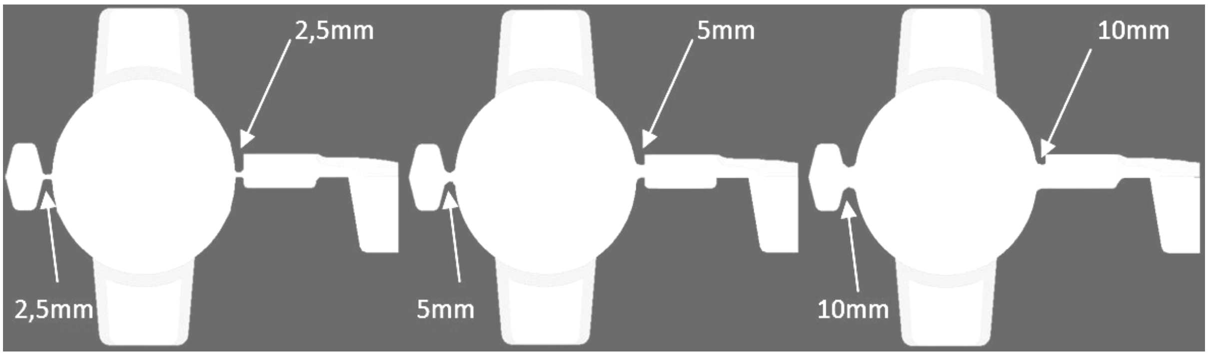

Figure 2. Variations of the ingate dimension, view from the top

Alloy Thermophysical properties:

- Casting temperature 600 °C or 760 °C (in other case)
- Specific heat at room temperature 0.76 kJ/kg K
- Specific heat at solidus temperature 1.05 kJ/kg K
- Liquidus temperature 565 °C
- Solidus temperature 507 °C
- Latent heat 500 kJ/kg

Heat transfer coefficients applied:

- Casting–mold 800 – 1000 W/m^{2}K
- Mold–cooling channel 1000–1500 W/m^{2}K
- Mold – chill 1000 W/ m^{2}K
- Chill – casting 2500-3000 W/m^{2}K
- Feeders (insulated)–mold 20-100 W/m^{2}K
- Mold – environment 30 W/m^2

3. RESULTS AND DISCUSSION

It is obvious that castings like this have large amounts of turbulence during filling, due to a design of a steep downsprue and complex shape of the piston. When the melt exits the ingate it makes a lot of splashes, turning back streamlines and entraps significant amounts of air. On the other side of the casting situation is the same, many complex melt fronts are established and a lot of air entrapment and oxide entrainment is formed, figure3. These air entrapments lasts for a few seconds that is enough for melt oxidation and formation of oxide skin (bifilm). Standard ingate dimension (thickness) for this casting is 5mm and there were also performed two more simulations with 2,5mm and 10mm ingate thickness to see the behavior of the melt during filling, figure 4.

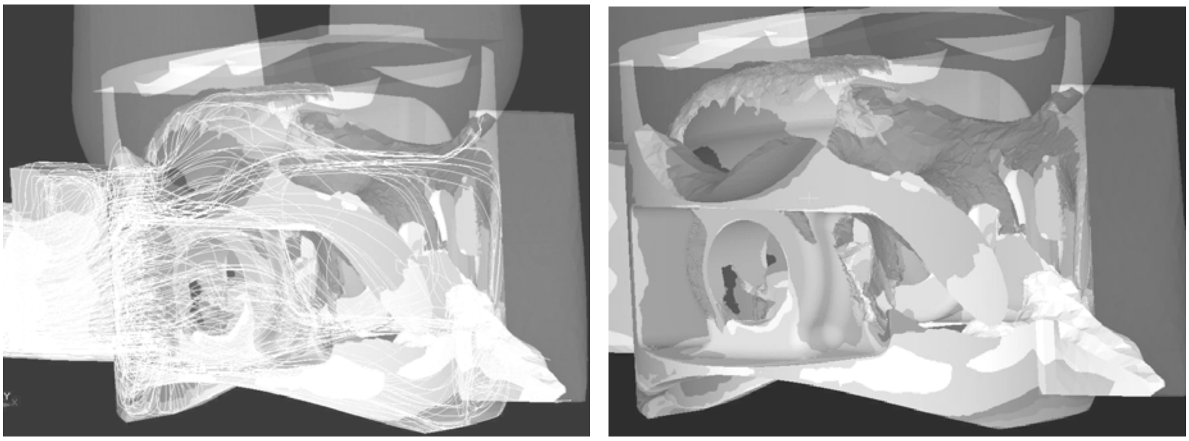

Figure 3. Streamlines and turbulent filling of the casting

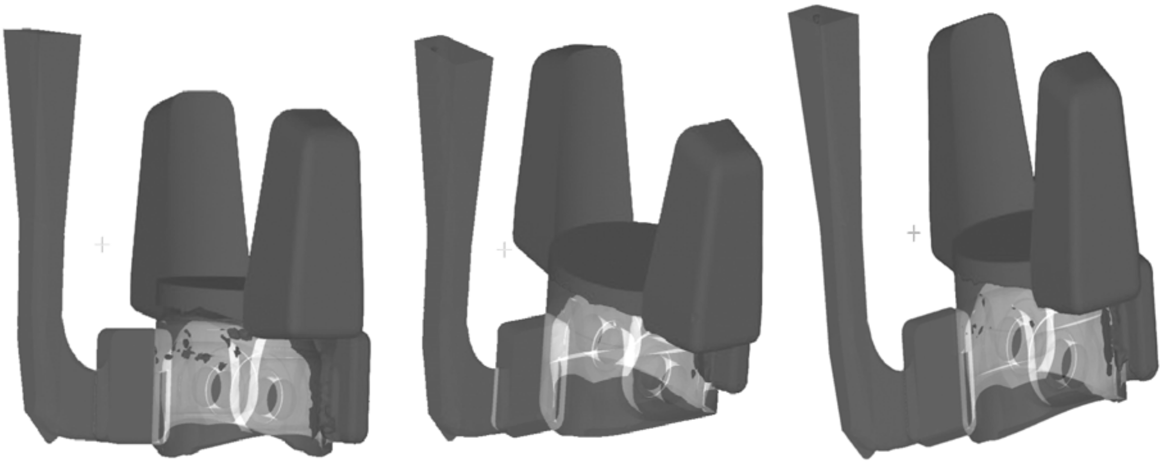

Figure 4. Air entrapment during filling the casting

Casting temperature 760°C - It was revealed that there are some dependences between air entrapment and application or lack of it, of the copper chills. The worst case of air entrapment was with ingate size of 10mm and with copper chills, left on figure4. In this case entrapments lasts for a 2,5 sec which is a long time.

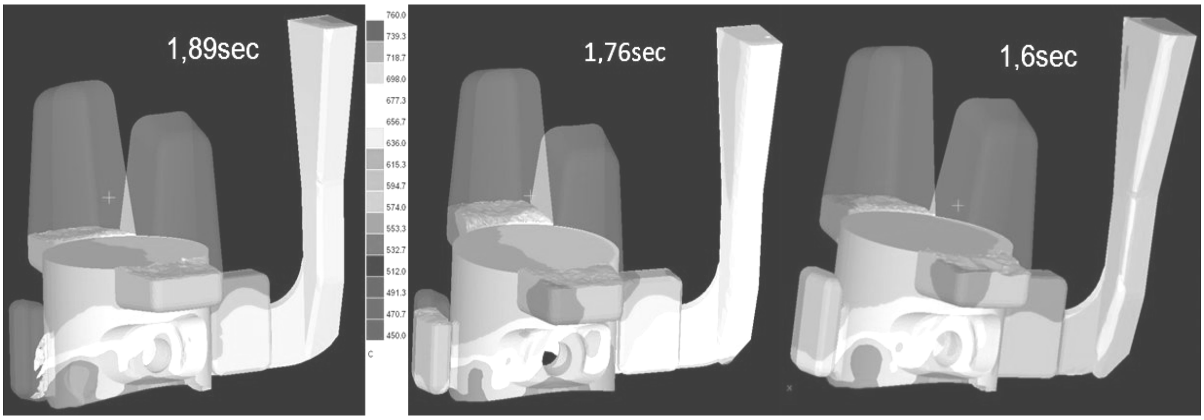

Figure 5. Temperature fields in same positions of filling front, different ingates dimensions (casting temp 760°C)

In cases when the ingate sizes were 2,5 and 5mm presence of air entrapment was significantly reduced and lasted much shorter(about 0,1sec) than it did with 10mm ingate, center and right on figure4. Increasing the dimensions of ingates violates the melt flow in manner that is more turbulent and the flow rates are higher thus some zones become prone to porosity formation, so called entrainment defects. On the other hand filling of the cold feeder is much faster and melt temperatures are higher, figure 5. It is also concluded that ingate size of a 10mm does not affect the feeding of the critical area, in other words there is no improvement [4].

Casting temperature 600°C - When the casting temperature was lowered we came to astonishing results in critical locations where porosity forms, observed earlier. Closer to the cold feeder where the copper chills are located melt forms large air entrapments or partial filling. These voids lasts in some cases just during filling, in other they are present until the casting finish solidification, and make a defect, figure 6. So in case of lower casting temperature and longer filling times the effective zones of chills came more liable to formation of defects like no other location in the casting. When reaching the back copper chills melt slows down because it’s mushy and begins solidification. When is appended the fact of air entrapment during filling, it is clear that these locations have two or three causes for defect formation.

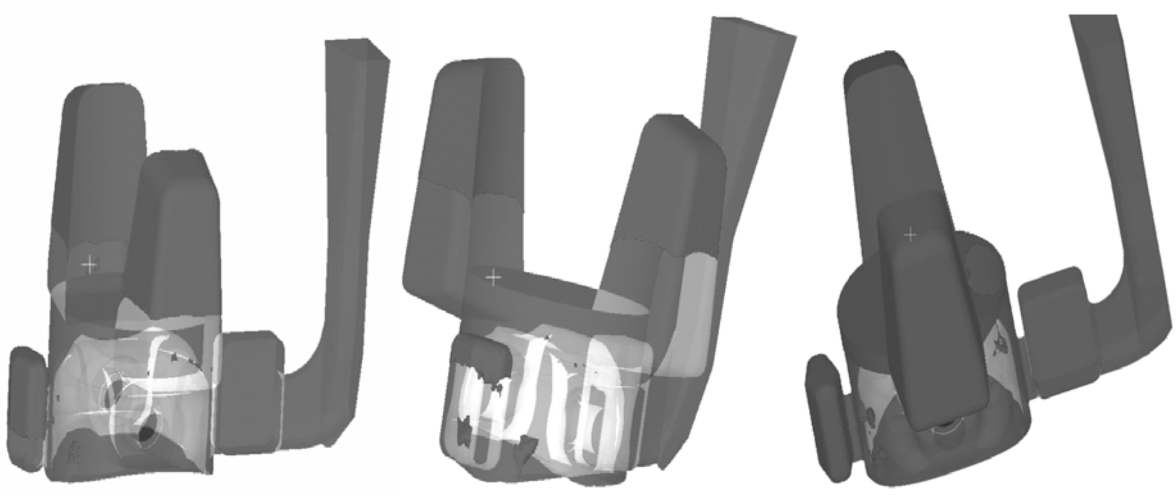

Figure 6. Air entrapment, casting temperature 600°C

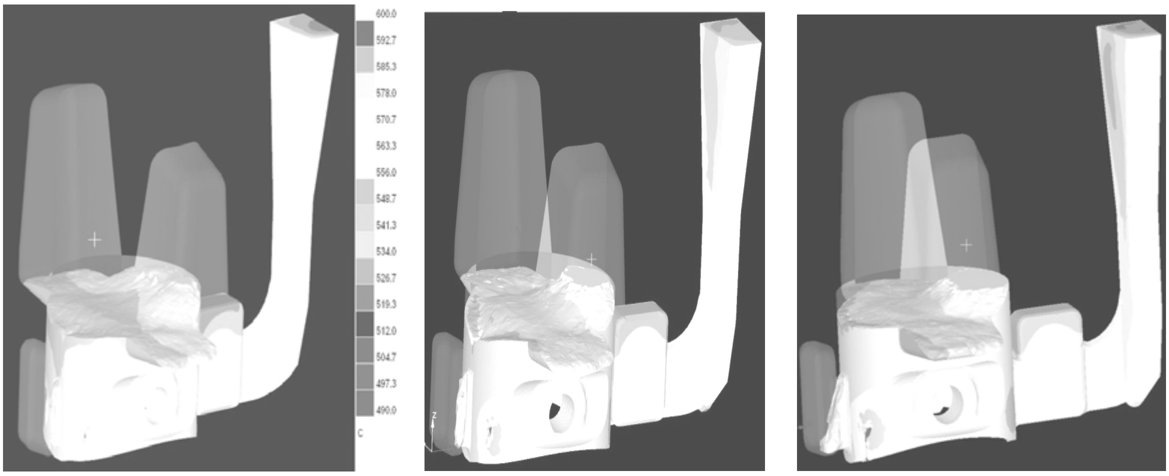

Figure 7. Temperature field and insufficient filling of the cavity, casting temperature 600°C

On the temperature field, figure 7 it is clearly visible that the melt reaches liquidise temperature in the vicinity of the chills, loses viscosity, and make insufficient filling of the mold. The worst case of inaccurate solidification, like before, is with 10mm ingates and copper chills. When a size of the ingate was 2,5 mm there was no defect formation but the filling of the cold feeder lasts much longer. Lower casting temperature make that casting with 5mm ingate had solidification problems to, in areas where the chills were applied, but not in amounts like with 10mm ingate, figure 7.

4. CONCLUSIONS

Result of various simulations undertaken lead to following conclusions:

- Dealing with porosity formation in aluminium castings demand multidisciplinary approach due to the complicated physics involved, which besides porosity includes such phenomena as fluid mechanics with phase change, macrosegregation in alloys, heat transfer between the casting and the mold etc.;
- Gating system design of this casting have crucial role in defect formation whereas there is a lot of melt turbulence during ingate exit and so on inducement of entrainment defect formation. Especially with 10mm ingate. Many overlaps of melt fronts took place near the cold feeder and at the braw of the piston which certainly creates gas entrainment defects;
- Detected porosity is influenced by copper chills and rapid cooling in their (critical) area;
- Lower casting temperatures have significant influence on accurate filling of the mold cavity and air entrapment primarily in vicinity of the copper chills. This scenario often

occurs in production due to variations in time that melt spends between being took from the furnace and 100% being filled into cavity;

- Combination of these multiple factors simultaneously influences casting quality and finding right balance between them is necessary in order to avoid porosity formation.

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