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COMPUTER SIMULATION AND EXPERIMENTAL RESEARCH OF CAST PISTON POROSITY

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ABSTRACT
Porosity is one of the big problems in the aluminum alloy casting industry, and as such this casting defect is closely studied. However majority of research is based on simple castings of little or no practical importance. The investigation described in this paper examined the porosity formation in the cast pistons, which were analyzed as a suited representative of a complex shape casting. For this reason, this research besides scientific could have great practical importance. The porosity was examined in detail using light microscopy as well as scanning electron microscopy and EDS. Same porosity problem was analyzed using computer simulations in order to study the influences of casting parameters on the porosity formation in pistons. Based on only a part of our results presented in the paper, significant correspondence between experimental and computer simulated results is obvious.
KEYWORDS
Porosity, casting, piston, computer simulation

1. INTRODUCTIONS

Aluminum castings have the increased use in the applications where the reduced weight and production cost play biggest role. The low expansion group of aluminum-silicon eutectic or near-eutectic alloys, also known as "piston alloys" provides the best overall balance of properties [1]. Cost reduction and product optimization have been the driving force for research in the field of reducing casting defects.

The porosity formation is the single most common defect in aluminum castings. These defects are the main reason of the majority of the scrap loss. More importantly in most cases defect is detected only after costly machining process.

There are several mechanisms for porosity formation: gas entrainment, gas precipitation during solidification and insufficient feeding (solidification shrinkage). Gas entrainment is, by nature, product of surface turbulence of the molten metal during mold filling. On the other hand the gas precipitation is defect caused by a residual gas in supersaturated initial melt. Since the hydrogen is the only gas dissolved to a significant extent in aluminum alloys, the hydrogen gas pore is the almost only gas precipitation defect occurring in these alloys. The solidification process of most commercial aluminum based alloys involves significant volume contraction; therefore the correct feeding is essential. According to Campbell [2] there are five distinct feeding mechanisms: liquid feeding, mass feeding, interdendritic feeding, burst feeding and solid feeding. Considering the good thermal conductivity and the large freezing range of the aluminum alloys the biggest impact on the pore formation is widely given to the interdendritic feeding. It should be noted that the shrinkage porosity is frequently initiated by a gas pore which acts like a seed.

Although the porosity formation phenomenon has been intensely studied there is no universal tool for predicting the appearance of this defect [3]. Lee et all in their paper [3] noticed two contradictions and apparent disagreement between the two group of authors. One group of authors is claiming that the porosity is reduced with the longer solidification time, but on the other hand there are researchers who found just the opposite – that the porosity content is decreasing with increasing solidification rate.

There are numerous attempts, especially in the last twenty years, to use the computer simulation in this respect, but the achieved results are not exact. This is mostly due to the nature of the casting process as a whole. Casting processes are very difficult to model 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. All these phenomena's are interconnected and can't be considered separately. Therefore to accurately predict porosity one must have accurate models for all of them. Computer simulation programs have recently become very powerful, but they are still far from perfect and exact. Therefore, the certain amount of workshop trail and error is sometimes still necessary. The use of optical as well as the electron microscopy is still indispensable tool in determining nature and the cause of porosity defects. Some important information can be also acquired from the local EDX analysis. Our paper is an attempt to combine all recent advances in this field of research and use it in the reduction of porosity in the real mass production environment. Acquired results and conclusions therefore not only have the scientific importance, but also the practical application.

2. METHODOLOGY

On the Figure 1 is shown the appearance of the examined cast piston immediately after ejection from the permanent mold. Filling and feeding system design is clearly visible. From the single pouring two pistons are cast at the same time. In front of the as cast pistons final shape of pistons after machining is also shown.

Figure 1. Appearance of the cast piston

Material of the piston is aluminum-silicon alloy who's composition is shown in the table 1.

Table 1. Chemical composition of Alloy K AlSi12CuNiMg

%Si	%Cu	%Ni	%Mg	%Fe	%Ti	%Mn	%Zn
11-13	0.8-1.5	0.8-1.3	0.8-1.3	Max 0.7	Max 0.2	Max 0.2	Max 0.2

Structure of casting and distribution of porosity was investigated on a polished cross section of the piston wall. The microstructure and morphology of the cross section was studied on LEITZ optical microscope. High magnification pores analysis was performed on the JEOL JSM 6460 LV scanning electron microscope with an embedded Oxford Instrument energy dispersive X-ray analyzer (EDS).

Computer simulation of the piston solidification was performed on the finite element software. Thermophisical properties of the alloy and the heat transfer coefficients used for the simulation are shown in the table 2. In order to regulate the solidification pattern the cooling channels were drilled in the permanent mold. For the same reason eight chills were also embedded in the mold, as shown in the figure 2.

Table 2. Simulation parameters

Alloy Thermophysical properties	
Liquidus temperature	565 °C
Solidus temperature	507 °C
Latent heat	500 kJ/kg
Specific heat at room temperature	0.76 kJ/kgK
Specific heat at solidus temperature	1.05 kJ/kgK
Heat transfer coefficients	
Casting – mold	800 – 1000 W/m²K
Mold – cooling channel	1000 – 1500 W/m²K
Mold – chill	1000 W/ m²K
Chill – casting	2500-3000 W/m²K
Feeders (insulated) – mold	20 -100 W/m²K
Mold – envirionment	30 W/m²K

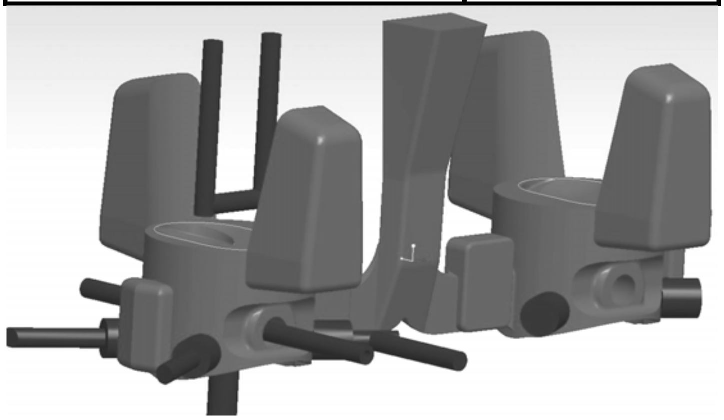

Figure 2. Placement of the cooling channels and the chills

3. RESULTS AND DISCUSSION

Main problem in the piston casting process (in our case) was appearance of porosity at the piston wall, figure 3. As it can be clearly seen the porosity is detected only after machining and is placed at the chill location in the near proximity of the colder feeder. On figure 3a arrow point on the location of the copper chill (see figure 2). On figure 3b group of pores average dimension of 0.5 mm is visible. Such porosity is detected on the approximately 25% of the cast pistons. We can not guarantee that the porosity does not exist on the other 75% of the pistons, but it is not detected after machining.

On the cross section of the piston wall with the porosity, figure 4, we made the cross section for the metallographic analysis, figure 5.

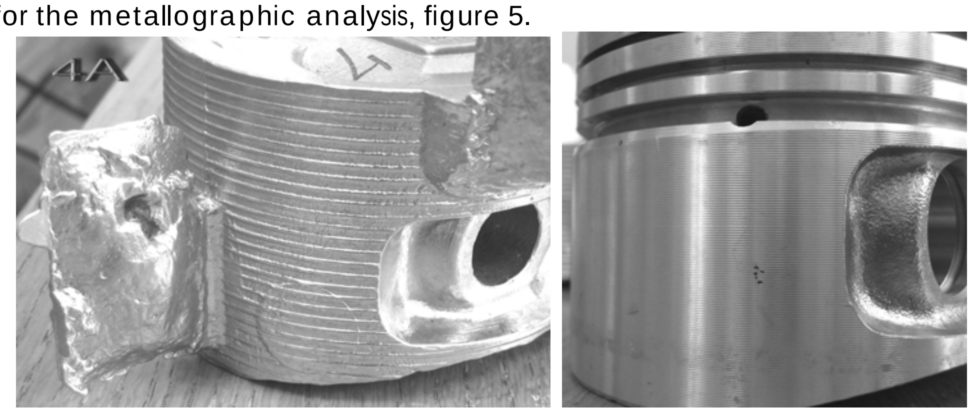

Figure 3. Porosity detected after machining

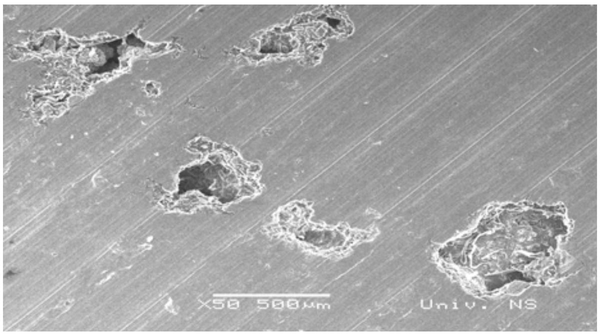

Figure 4. SEM image of detected porosity at the surface of the piston wall

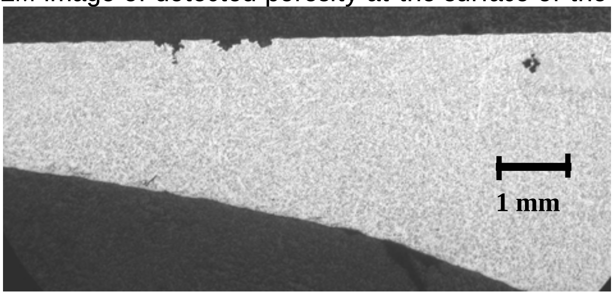

Figure 5. Cross section of the piston wall

Figure 5 shows that the porosity is formed in the immediate surface proximity and is therefore detected only after machining. One detected pore is still under the machined surface and therefore not visible from the outside.

It should be noted that the porosity is formed on the thinnest part of the piston wall.

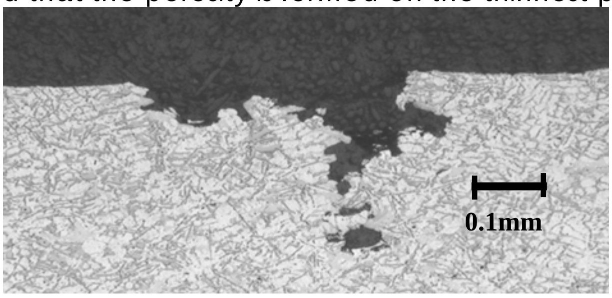

Figure 6. Microstructure of the piston wall near detected porosity

Microstructure is identical in the whole cross section of the piston wall and typical for this aluminum-silicon alloy, figure 6. Shape of the pores indicates the shrinkage, not the gas, porosity. For the more detailed analysis of the porosity we used SEM microscopy.

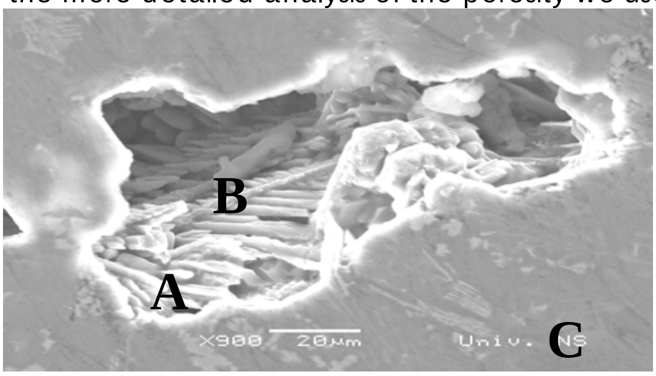

Figure 6. Microstructure of the piston wall near detected porosity

Typical inside surface morphology of the pore is given on the figure 6. Presence of the dendrites and interdendritic space is clearly visible. Dimension of secondary dendrites arms spacing suggests the rapid cooling and small local solidification time. On the locations of the letters A, B and C the EDS analysis was performed, table 3.

Table 3. Results of the EDS analysis

	%O	%F	%Mg	%Al	%Si	%Mn	%Fe	%Ni	%Cu	Rest
A	3.74	-	3.67	58.8	8.11	0.97	5.68	12.09	6.93	-
B	3.2	1.3	1.78	53.35	3.41	1.56	9.63	21.31	4.45	-
C	-	-	1.15	59.87	10.61	0.35	1.11	2.75	2.34	21.82

Presence of the oxygen on the pore inside surface could be explained with the presence of the certain amount of dissolved oxygen in the melt. It confirms the fact that there is no possibility of any contact of the pore inside surface with the atmosphere before cooling is finished. After cutting the pore and the surface of the piston wall were exposed to the same environment influences.

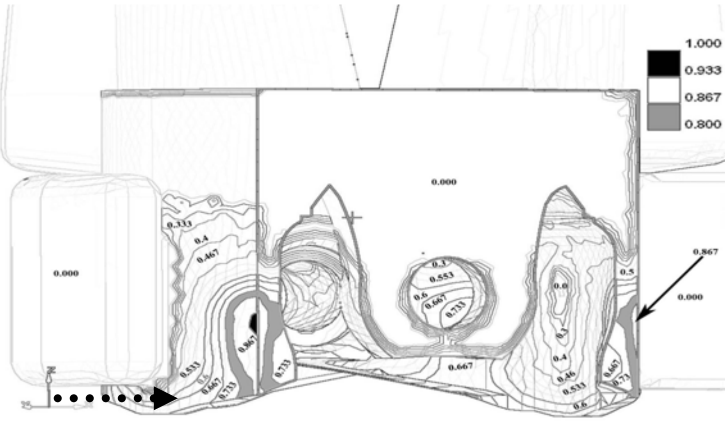

Figure 7. Fraction solid after 11.4 sec from start of filling – 1st variation

1st variation of computer simulation – with the copper chills and the 5mm wide feeder neck. It is visible that first trace of the solidification front is detected on the chill – casting contact on the thinnest part of the wall. In the near proximity of this zone there exist the feeder with the above liquidus temperature. On the cross section of the wall it is visible that the porosity zone directly corresponds to place where the 100% of fraction solid first appears. It means that porosity is concentrated near the outer piston wall (see figure 5).

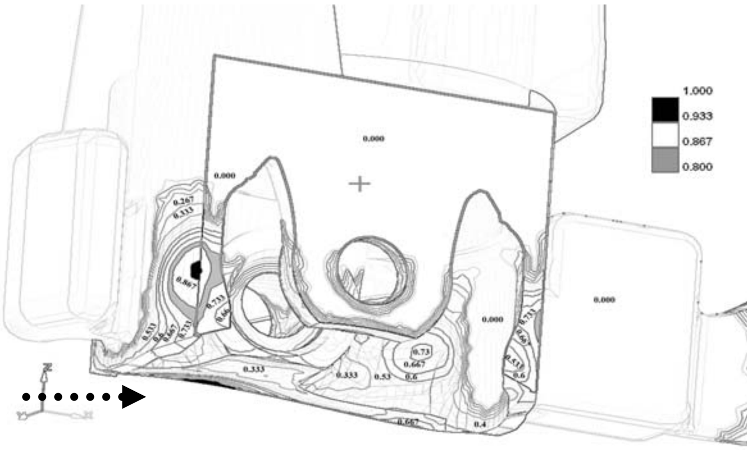

Figure 8. Fraction solid after 10.4 sec from start of filling – 2st variation

2st variation of computer simulation – with the copper chills and the 10mm wide feeder neck. The place and the shape of first appearance of the 100% of fraction solid is the same as in 1st variation. The main difference in this simulation is the cooling rate, because the first appearance of the 100% of fraction solid is after 10,4 seconds. The difference in the time can be explained by the faster mold filling due to wither ingate and feeder neck.

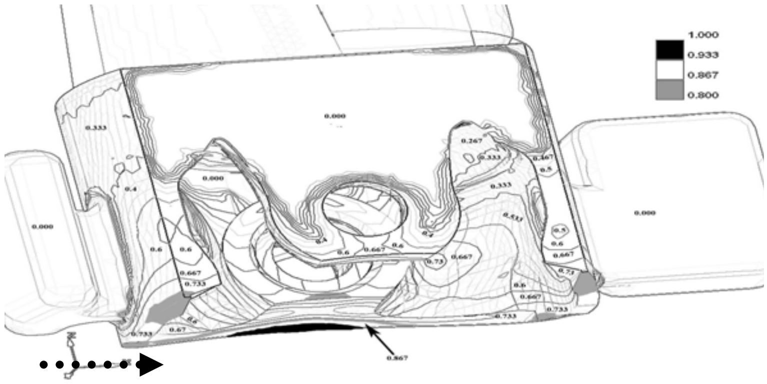

Figure 9. Fraction solid after 20.5 sec from start of filling – 3st variation

3st variation of computer simulation – without the copper chills and the 10mm wide feeder neck. First appearance of the 100% fraction solid is registered at the mould bottom. The solidification front spreading corresponds to the filling of melt in permanent mould. The solidification rate is considerably lower and the time of 100% fraction solid appearance is almost doubled to 20.5 seconds.

Wish to achieve faster solidification and higher productivity of permanent mold casting machine made the piston manufacturer use the chills which considerably reduce the solidification time. But the chill presence increases the risk of porosity appearance at the zone of copper chill effects. Our experimental research showed that the presence of copper chills is not as critical on the zone of hot feeder near the ingate as is in the proximity of hot feeder on the other end. It can be explained by the melt temperature difference near hot feeder closer to the ingate. Interdendritic feeding strongly depends on the temperature gradient and the cooling rate [3].

4. CONCLUSIONS

The following conclusions may be drawn from the results of the present investigation:

1. Porosity formation is big problem for aluminum-silicon alloy castings, especially when appears on the finally machined surface.
2. Metallographic analysis showed that the group of pores is primarily located near the cast surface near the zone of the copper chills.
3. Computer analysis of the solidification process clearly showed the influence of the chill on the solidification front. Those places are also the same with the pleases where the porosity is detected.
4. Four the same copper chill is placed to cool the casting outer wall, but the chills near the cold feeder are more prone to porosity, which is confirmed with the computer simulation.
5. Computer simulation showed that the amount of formed porosity can be reduced by variation of the dimensions of the feeder neck and ingate.

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