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USE OF SEM AND EDS ANALYSIS IN THE INVESTIGATION OF Al-Si-Cu PISTON ALLOY CAST POROSITY

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Porosity formation was detected in the casting thinnest section in the proximity of the as cast surface and near the wall centerline. In order to investigate the cause of the porosity formation light microscopy was used to define as cast structure. After initial findings SEM and EDS analyses were performed. Based on the results it is possible to define cause of the observed porosity. A number of pores originates from the mould filling stage and entrainment of the oxide films, while others appear due to insufficient feeding during solidification.

Key words: casting, porosity, piston, SEM, EDS

Primjena SEM i EDS analiza u istraživanju poroznosti Al-Si-Cu lijevanog stapa. Kod najtanjeg presjeka stijenke odljevka otkrivena je pojava poroznosti neposredno ispod površine stijenke, kao i u zoni sredine stijenke. Kako bi se utvrdio uzrok pojave poroznosti primijenjena je svjetlosna mikroskopija za određivanje lijevane strukture. Nakon prvobitnih opažanja provedene su SEM i EDS analize. Na temelju dobivenih rezultata moguće je odrediti uzroke nastanka otkrivene poroznosti. Određeni broj pora nastaje zbog zarobljavanja oksidnog filma tijekom faze popunjavanja kalupa, dok je ostatak poroznosti posljedica neadekvatnog napajanja tijekom skrućivanja.

Ključne riječi: odljevak, poroznost, stap, SEM, EDS

INTRODUCTION

Most common defect in aluminum permanent mould casting is porosity. There are several mechanisms of porosity formation: gas entrainment, gas precipitation during solidification and insufficient feeding (solidification shrinkage).

Gas entrainment is, by nature, product of surface turbulence of molten metal during mold filling while 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 [1], the hydrogen gas pores are 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 [1] there are five distinct feeding mechanisms: liquid feeding, mass feeding, interdendritic feeding, burst feeding and solid feeding.

Considering good thermal conductivity and large freezing range of 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 [2, 3, 4] there is no universal tool for predicting the appearance of this defect [5]. Lee et all in their paper [5] noticed two contradictions and apparent disagreement between the two groups of authors. One group of authors claims 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. These contradictions are consequence of high complexity of the casting process.

This paper studies porosity formation in cast pistons produced from Al-Si-Cu alloy. Porosity location is very unusual since it appears in the castings thinnest section with wall thickness of about 3,5 mm. It is grouped in relatively narrow zone and it is detected only after machining process.

The main problem, and aim of this investigation, is to define the origin of porosity formation and hence eliminate inducements that affect its presence. Earlier mould filling and casting solidification computer analyses [6] confirmed that these locations are prone to air entrainment defects and shrinkage porosity formation. They also revealed that amount of formed porosity can be reduced by variation of dimensions of a feeder neck and ingate, or by application of adequate chills at critical

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locations [6]. Presented work gives results of detailed SEM and EDS investigation of found porosity.

EXPERIMENTAL WORK

The pistons analyzed in this study are cast into two cavity steel mould. Appearance of the cast piston after machining process is shown in Figure 1. Material of the cast pistons is aluminum – silicon – copper alloy K AlSi12CuNiMg modified with phosphorous. Chemical composition of the alloy is given in Table 1.

Figure 1. Machined piston with found porosity – see arrow

Table 1. **Chemical composition of Alloy K AlSi12CuNiMg**

Element	Si	Cu	Ni	Mg
w, %	11 ÷ 13	0,8 ÷ 1,5	0,8 ÷ 1,3	0,8 ÷ 1,3
Element	**Fe**	**Ti**	**Mn**	**Zn**
w, %	max. 0,7	max. 0,2	max. 0,2	max. 0,2

After the first visual inspection, representative samples were removed from various locations of the pistons.

Each sample was ground and polished in order to study the microstructure and distribution and morphology of porosity in wall cross section.

The polished samples were then etched for 3 seconds using a 1% water solution of hydrofluoric acid (HF).

Microstructure and morphology of the cross section were 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). Analysis was preformed both before and after the etching of the samples.

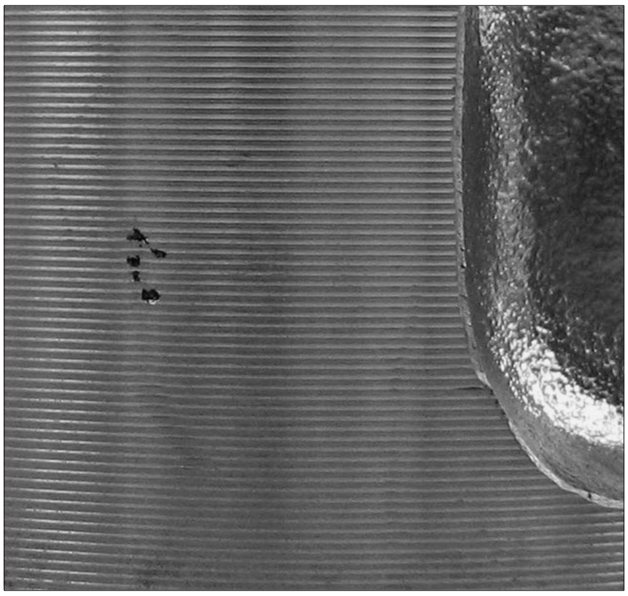


Figure 2. Detail view of surface porosity

RESULTS AND DISCUSSION

Analyzed porosity with average size of the visible pores approximately 0,5 mm in diameter was clearly visible on the 25 % of the cast pistons. Since the pistons were not analyzed by x-rays porosity may also be present in the remaining 75 % of the cast pistons. Machining process did not reveal it, but that does not mean that porosity is not present.

Typical appearance of the porosity zone is shown in Figure 2. It can be seen that the porosity zone consists of the group of pores.

In order to thoroughly analyze shape, microstructure and chemical composition of the pores, cross section of the piston wall at the place of the porosity was made, Figure 3.

Two groups of porosity are clearly visible, and are here denoted as type A and type B porosities. Type A porosity is formed in the immediate surface proximity and is therefore detected after machining. Type B porosity is under the machined surface and therefore not visible from the outside.

As cast microstructure of the wall is typical for the examined aluminum-silicon-copper alloy, Figure 4. It consists of the aluminum dendrites, primary and eutectic silicon and Al-Ni, Al-Ni-Cu and Mg-Si intermetalic phases.

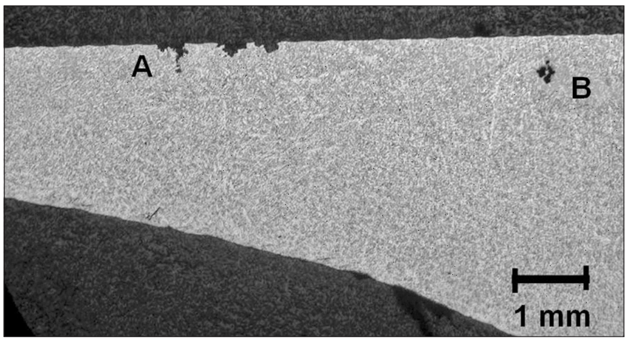


Figure 3. Cross section of the piston wall

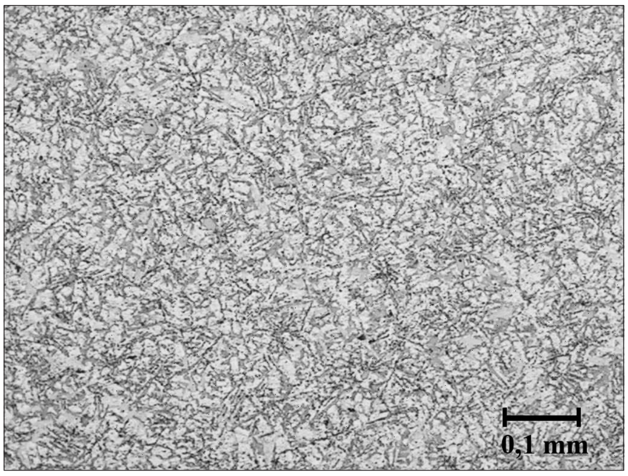


Figure 4. As cast microstructure

SEM analysis showed irregular shape of type A pores, Figure 5. This indicates that the mechanism of gas precipitation is not plausible source of the porosity formation. Likewise, solidification shrinkage is not a likely source since the pores are in the proximity of the wall's thinnest section and copper chills. Likely explanation of this kind of porosity is gas entrainment process. It explains both the irregular morphology of the pore's inner surface and the porosity location.

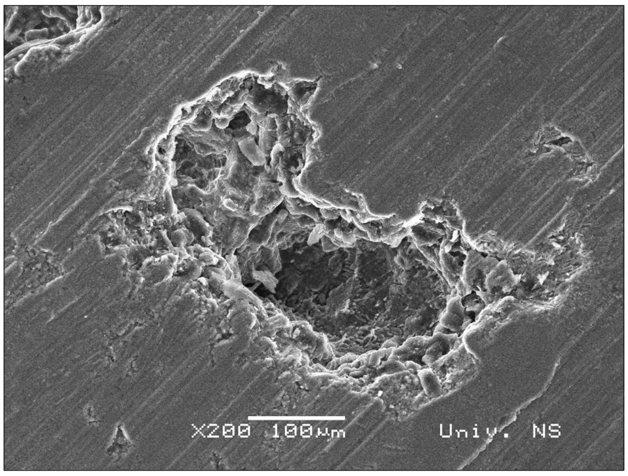
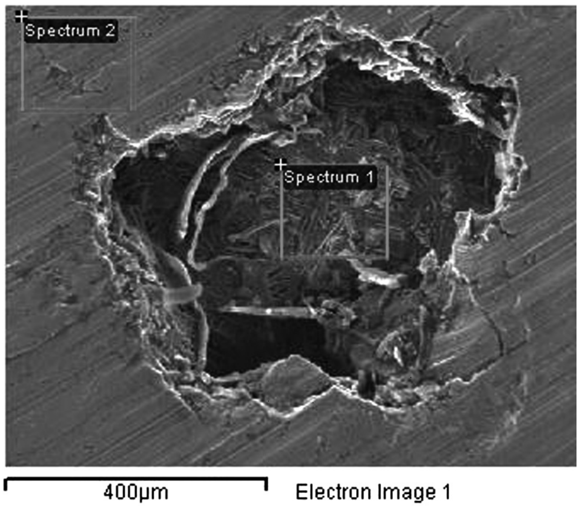


Figure 5. Secondary electron image of the type A porosity

The explanation is confirmed by EDS analysis shown in Figure 6 and by computer simulation [6].

Secondary electron image of type B porosity is shown in Figure 7. Although found in proximity of A type porosity its morphology indicates different formation mechanism. Pores inner surface is clearly dendritic. Oxide bifilm is not visible and entrainment process is therefore not probable cause. The pore is most likely formed due to solidification shrinkage.

Similar conclusion can be also drawn from the EDS analysis shown in Figure 8. Higher concentration of solutes Cu, Mg, Ni and Fe suggests that this is the location of solidification of last solute-rich liquid.



Element	*w*, %	
	Sp. 1	Sp. 2
Al	61,4	75,25
Si	9,21	11,54
Ni	5,38	1,48
Cu	4,49	1,49
Mg	2,79	2,07
Fe	2,94	1,23
Mn	0,5	0,264
O	12,9	6,03
Zn, Ag, N Balance	0,04	0,07

Figure 6. EDS analysis of the type A porosity

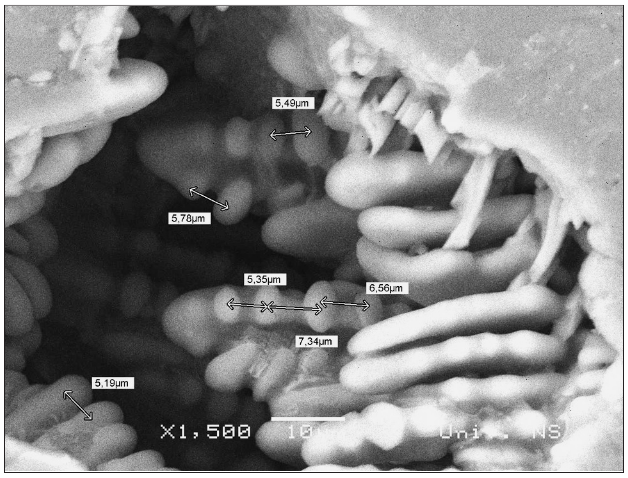
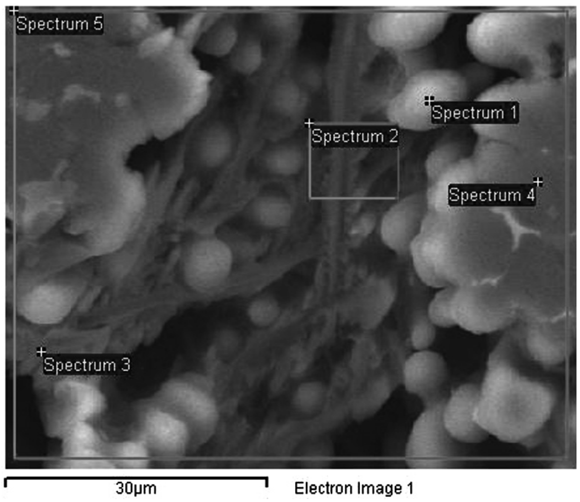


Figure 7. Secondary electron image of the type B porosity

CONCLUSION

SEM and EDS analyses undoubtedly confirmed different causes of the porosity formation although the pores have similar dimensions. The shape and chemical composition of the pores inner surfaces indicates that type A pores are formed because of air entrainment dur-



Element	w, %				
	Sp. 1	Sp. 2	Sp. 3	Sp. 4	Sp. 5
Al	83,35	66,51	80,3	84,19	75,45
Si	1,53	3,22	2,77	1,41	5,19
Ni	-	11,28	0,49	0,13	4,9
Cu	0,96	3,69	1,8	0,96	3,68
Mg		-	0,7	-	-
Fe	-	6,96	0,36	-	2,69
Mn	-	0,99	-	0,36	0,54
O	14,16	7,34	13,57	12,96	7,55

Figure 8. EDS analysis of the type B porosity

ing filling stage and type B pores were formed due to insufficient feeding during solidification.

To eliminate the presence of revealed porosity it is necessary to combine experimental results with computer simulation of the casting process. Subsequent computer simulation is greatly simplified and more accurate if the SEM and EDS analyses first provide insight into the phenomena and causes of porosity formation.

REFERENCES

[1] J. Campbell, Castings, Butterworth-Heinemann, Oxford, 2003, 1-16 and 212-222.
[2] K. D. Carlson et al, Materials Science Forum, 519-521 (2006), 1699-1706.
[3] A. Reis et al, Journal of Materials Processing Technology, 202 (2008), 428-434.
[4] P.D. Lee, A. Chirazi, D. See, Journal of Light Metals, 1 (2001), 15-30.
[5] Y.W. Lee, E. Chang, C.F. Chieu, Metallurgical transactions B, 21B (1990), 715-722.
[6] D. Kakas, L. Kovacevic, P. Terek, Annals of the faculty of engineering Hunedoara, V (2007), 179-184.

List of symbols

SEM Scanning Electron Microscopy
EDS Energy Dispersive Spectroscopy
w mass percent, %

Note: Responsible translator: Tihana Saveljić, professor of English language, Novi Sad, Serbia.