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The Microstructure of AlSi9Cu3 Alloy after Different Stages of Liquid Metal Preparation

Ł. Poloczek*[a], B. Dybowski[b], M. Łuszczak[c], A. Kiełbus[b]
[a] Department of Production Engineering, Materials Engineering and Metallurgy Faculy
Silesian University of Technology, Krasińskiego 8 STR, 40-019 Katowice, Poland
[b] Institute of Materials Science, Materials Engineering and Metallurgy Faculy
Silesian University of Technology, Krasińskiego 8 STR, 40-019 Katowice, Poland
[c] Nemak Poland Sp. z o.o. Komorowicka 53 STR, 43-300 Bielsko-Biała, Poland
*Corresponding author. E-mail address: lukasz.poloczek@polsl.pl

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Abstract

Aluminium alloys are one of the most important casting alloys. Among them, the Al-Si alloys comprise perhaps the most important group – about 80% of the aluminium casts are made of them. These materials are characterized by a very good technological properties, good corrosion resistance and tribological properties. Their main disadvantage is, however, presence of the massive, brittle silicon crystals. They significantly affect alloys mechanical properties. Liquid metal treatment is essential for modification of Al-Si eutectic structure. The following work presents results of the research on the microstructure of the AlSi9Cu3 alloy after different stages of liquid metal preparation. Three casting processes have been conducted, chemical composition of the material in each case was in agreement with EN 1706 specification. During each casting process, three specimens were gravity cast: first, made from pure ingots; second, after the scrap addition and third one after the liquid metal treatment. Qualitative and quantitative evaluation of the microstructure was done on each specimen. Specimens cast from pure ingots are characterized by a refined Al-Si eutectic microstructure. After scrap addition, the silicon crystals became morphology of the massive platelets. What is more, intermetallic phases observed within the structure posses different morphologies after different stages of liquid metal preparation. After scrap addition, increased gas porosity was observed. Liquid metal treatment reduced slightly the formation of gas pores.

Keywords: Metallography, AlSi9Cu3 alloy, Microstructure, Scrap, Liquid metal treatment

1. Introduction

Aluminium alloys are one of the most important casting alloys. They are characterized by a low density, high mechanical properties and very good casting properties [1, 2]. Among all aluminium alloys, Al-Si group is perhaps the most important. Elements cast from Al-Si alloys have to exhibit high mechanical properties and technological as well as utility properties. The most important factor determining castings quality is liquid metal treatment [3]. Faulty liquid metal treatment results in formation of casting defects, mainly non-metallic inclusions and porosity. Non metallic inclusions may get into the liquid metal from input material (scrap), they may also originate in chemical reactions occurring during the smelting process and in reactions between the liquid metal and mould.

Gas porosity originate mainly in hydrogen, which is formed during alloy solidification. The porosity may also originate in impurities getting into the liquid metal, such as oils and greases present on scrap material. Liquid metal treatment may significantly reduce formation of the porosity. The most important refining gases are nitrogen or argon. The gases are introduced into the liquid alloy with lance. In the bubbles, formed within the liquid, hydrogen partial pressure is close to zero, which leads to diffusion of this element to the bubbles. The gas is then removed with the bubbles from the melt [4, 5]. Alloy's refining is thus essential for achievement of acceptable mechanical and technological properties [6].

Iron in the aluminium alloys is said to be an impurity. However in case of high pressure die casting, it facilitates releasing of the cast from the die. For this reason, about 0.8 wt. % is intentionally added to the alloys used for HPDC process. This element may form brittle, acicular precipitates of β-Al_5FeSi, which reduces mechanical properties of the alloy, as well as facilitates formation of porosity. Elements such Mg or Mn suppress formation of β-Al_5FeSi in favour of relatively harmless α-$Al_{15}(Fe,Mn,Cr)_3Si_2$ and π-$Al_8Mg_3FeSi_6$ [7-10].

2. Material for the research and methodology

AlSi9Cu3 aluminium alloy was investigated. Three smelting processes were done for the research. During each process, three specimens were gravity cast: first, after melting of pure ingots (A1, B1, C1), second one after addition of scrap material (A2, B2, C2) and third one after liquid metal treatment (A1, B1, C1). Chemical composition in each case was in accordance with EN 1706 specification (Tab. 1).

Microstructure observations were done on microsections prepared with following procedure: grinding on the SiC abrasive papers with grades 80-1200 followed by polishing on the diamond suspensions with mean grain size 6μm, 3μm and 1μm. Final polishing was done on colloidal silica suspension with grain size 0.05μm. Observations were done on un-etched specimens.

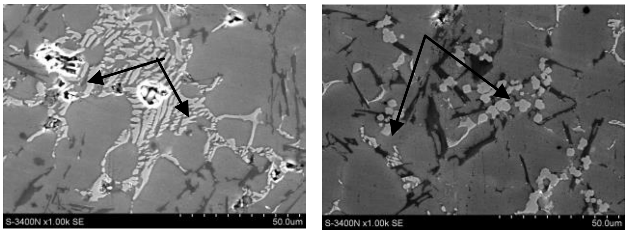
Microstructure observations were conducted on Olympus GX71 optical microscope as well as on Hitachi S3400N scanning electron microscope. Chemical composition of the structural constitutes was analysed with Thermo-Nolan energy dispersive spectrometer. Quantitative analysis was conducted in each case on 20 images, recorded on optical microscope with magnification of 500 times.

3. Research results

3.1. AlSi9Cu3 alloy's microstructure

AlSi9Cu3 alloy's microstructure consist of Si and Cu rich α-Al solid solution dendrites. The main eutectic mixture is a binary α-Al+β-Si eutectic. Depending on the stage of liquid metal preparation, the β-Si was characterized by a fibrous or platelet-like morphology. Within the interdendritic regions other intemetallic phases with different morphologies were observed (Fig. 1).

Phases characterized by a Chinese-script or irregular eutectic morphology contain Al and Cu or Al, Si, Cu and Mg. These are most probably θ-Al_2Cu and Q-$Al_5Mg_8Cu_2Si_6$ phases. Polygonal particles contain Al, Si, Fe as well as Mn, which indicates α-$Al_{15}(Fe, Mn)_3Si_2$ phase. This phase may also occur with Chinese-Script morphology [9, 11]. Massive, acicular phases consist of Al, Si and Fe, they are most probably β-Al_5FeSi particles. In the alloy's microstructure may also be observed π- $Al_8Mg_3FeSi_6$ [9]. The α and β Fe containing phases may have different sizes – from fine particles formed in complex eutectic reactions to much more massive precipitates formed in ternary, sometimes binary reactions [11, 12].



a) b)

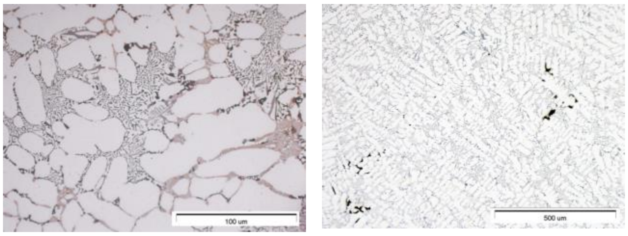
Fig. 1. AlSi9Cu3 alloy microstructure, SEM, SE; a) intermetallic phases with eutectic morphology; b) polygonal precipitates

Table 1.
AlSi9Cu3 alloy chemical composition after different stages of liquid metal preparation (wt. %).

Specimen	Al	Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Sn	Pb	Na	Zr
EN 1706	Bal.	2.0 ÷ 4.0	8.0 ÷ 11	0.05÷0.55	<0.55	<1.3	< 0.25	<0.55	<1.2	< 0.25	< 0.35	< 0.05	< 0.05
A1	85.67	3.31	8.62	0.29	0.24	0.73	0.041	0.072	0.885	0.020	0.066	0.0003	0.0070
A2	86.54	2.87	8.34	0.22	0.28	0.73	0.042	0.050	0.802	0.017	0.059	0.0008	0.0096
A3	86.67	2.89	8.12	0.18	0.26	0.75	0.040	0.075	0.884	0.017	0.059	0.0009	0.0068
B1	86.85	2.78	7.99	0.26	0.24	0.68	0.027	0.079	0.975	0.018	0.065	0.0002	0.0045
B2	86.99	2.75	8.01	0.24	0.26	0.69	0.035	0.058	0.845	0.017	0.062	-	0.0081
B3	86.76	2.81	8.14	0.24	0.26	0.71	0.043	0.061	0.856	0.018	0.064	0.0002	0.0079
C1	86.58	2.94	8.09	0.25	0.22	0.69	0.029	0.087	1.004	0.017	0.064	-	0.0047
C2	86.66	2.73	8.22	0.25	0.34	0.93	0.054	0.065	0.647	0.017	0.064	-	0.0047
C3	86.36	2.84	8.32	0.24	0.35	0.98	0.053	0.068	0.674	0.013	0.054	-	0.0092

3.2. AlSi9Cu3 alloy's microstructure after different stages of liquid alloy preparation

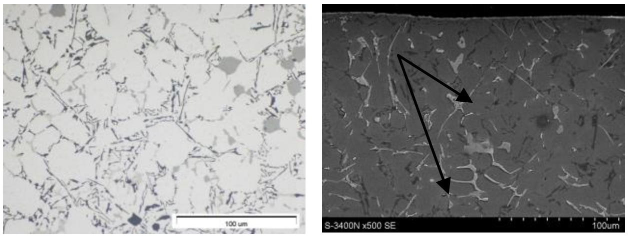
Microstructure of the alloy cast from pure ingots in each smelting process is similar. The α-Al+β-Si eutectic posses fibrous morphology. The intermetallic phases occurring in the interdendritic regions are characterized by a Chinese-script morphology or morphology of irregular eutectics (Fig. 2a). There are not observed any coarse β-Al_5FeSi particles. Specimens cast from pure ingots are free from significant gas porosity, some microshrinkages are observed (Fig. 2b).



a) b)

Fig. 2. Microstructure of AlSi9Cu3 alloy cast from pure ingots, OM; a) shrinkage porosity; b) morphology of the α-Al+β-Si eutectic and intermetallic phases

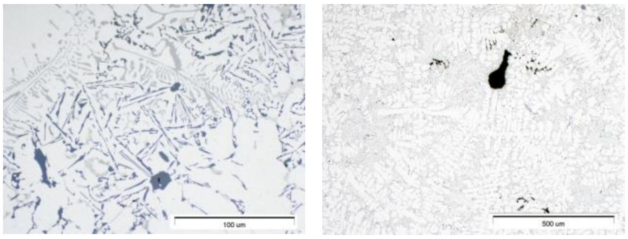
Alloy cast after scrap remelting is characterized by different morphology of the α-Al+β-Si eutectic. β-Si crystals occur as a massive platelet-like particles (Fig. 3a, b). In case of A and C smelting processes change in morphology of intermetallic phases was also noticed. In the A smelt, numerous precipitates of the polygonal α-$Al_{15}(Fe,Mn,Cr)_3Si_2$ phases were observed (Fig. 3a). On the other hand, in the C smelt increase of the large, Chinese-script phases was observed. What is more, presence of the massive, acicular β-Al_5FeSi was noticed (Fig. 3b). Number of large gas pores increased after scrap remelting.



a) b)

Fig. 3. Microstructure of the alloy after strap remelting; a) Morphology of the α-Al+β-Si eutectic, OM; b) β-Al_5FeSi Needles, SEM, SE

Microstructure of the alloy after barbotage treatment is also changed. β-Si crystals are slightly larger than after scrap remelting. In the A smelt, slight decrease in a number of polygonal α-$Al_{15}(Fe,Mn,Cr)_3Si_2$ phases was observed. Intermetallic phases possessing Chinese-Script morphology grow (Fig. 4a), while number of β-Al_5FeSi phase did not decreased. Refining decreased gas porosity only in small degree, within the structure large, regular pores are still observed (Fig. 4b).



a) b)

Fig. 4. Microstructure of AlSi9Cu3 alloy after liquid metal refining, OM; a) gas pores; b) Phases morphology

3.3. Quantitative microstructure evaluation

Results of the quantitative evaluation of phases stereological parameters are shown in the tables 2 and 3. Eutectic Si volume fraction depends on the Si content in the alloy, not on the stage of liquid metal preparation. Increase of the inhomogenity of the eutectic regions is observed after barbotage treatment. Increase of the silicon flat section was observed after scrap remelting and after alloys refining. Intermetallic phases parameters depends on the chemical composition of the alloy, not on the stage of liquid metal preparation.

Table 2.
Eutectic Si and intermetallic phases volume fraction

Specimen	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
Eutectic silicon									
Volume fraction V_V [%]	8.69	8.32	7.46	6.21	8.44	11.2	7.58	7.74	8.23
Variability factor $\upsilon(V_V)$ [%]	8.53	8.57	11.6	9.72	8.99	16.6	10.8	13.3	17.1
Intermetallic phases									
Volume fraction V_V [%]	4.8	8.32	4.93	7.08	5.07	5.8	5.57	5.39	4.99
Variability factor $\upsilon(V_V)$ [%]	21.4	8.57	8.54	14.1	15.9	16.1	21.5	17.4	31.9

Table 3.
Metallographic parameters of phases.

Specimen	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
Eutectic silicon									
Average area of the flat section A [μm^2]	5.48	7.39	6.21	3.35	5.56	11.2	6.4	7.24	8.76
Variability factor $\upsilon(A)$ [%]	163	138	142	158	162	16.6	175	142	150
Intermetallic phases									
Average area of the flat section A [μm^2]	9.46	11.4	6.94	6.71	6.53	8.81	7.52	7.65	9.17
Variability factor $\upsilon(A)$ [%]	242	251	164	289	197	214	213	239	218
Shape factor ξ [-]	0.73	0.73	0.70	0.74	0.73	0.72	0.71	0.75	0.69
Elongation δ [-]	2.14	2.08	2.18	2.07	2.11	1.99	2.08	2.12	2.24

3.3. Discussion

Chemical composition of each specimen is in accordance with EN 1706 specification. The investigations revealed that even such slight differences in the alloying elements content causes important changes in AlSi9Cu3 alloy's microstructure. It can be easily seen on the example of iron. Increase of Fe content from about 0.7% up to about 0.9% causes formation of massive, brittle acicular particles of β-Al_5FeSi phase. In this case increase of Mg or Mn content should suppress formation of the β phase.

Volume fraction of the eutectic Si strongly depends on silicon content within the alloy, not on the stage of liquid metal preparation. Microstructure of the castings prepared from the pure ingots is characterized by fine β-Si fibres (A=3.35 to $6.4\mu m^2$). After following operations (scrap remelting, liquid metal refining) eutectic β-Si phase formed massive platelets (A=6.21 to $11.2\mu m^2$). Mean area of intermetallic phases increased in the A smelt after scrap remelting, which is caused by formation of coarse α-$Al_{15}(Fe,Mn,Cr)_3Si_2$ phases precipitation. After barbotage treatment, as the coarse phases quantitiy decreased, the mean area of the phases flat section decreased. This is confirmed by a change in intermetallic phases elongation (decreased after strap remelting). In the case of smelt C, surface area of the intermetallic phases flat section increases both after scrap addition and after liquid metal refining. Shape factor of these phases decreases, which suggests morphological changes. After scrap addition, harmful β-Al_5FeSi phases are observed. Only during the smelt B intermetallic phases did not undergo distinct morphological changes. The chemical composition of the alloy was not changed in a major way. This indicates that scrap added during the process was characterized by a high quality and purity. However, the expansion of the eutectic Si particles also in this case indicates, that modification of the alloy in further stages of liquid metal preparation is essential. Scrap remelting caused major increase in gas porosity within the alloy's microstructure. Numerous, large gas pores are observed in the structure. These pores were not observed in alloys cast from pure ingots. Barbotage treatment did not cause complete degasification of the alloy. Process parameters should be optimized.

4. Conclusions

1. Microstructure of the AlSi9Cu3 alloy consists of α-Al dendrites, α-Al + β-Si binary eutectic and α-$Al_{15}(Fe,Mn,Cr)_3Si_2$, β-Al_5FeSi, θ-Al_2Cu, π-$A_8Mg_3FeSi_6$ and Q-$Al_5Mg_8Cu_2Si_6$ intermetallic phases fordem in complex eutectic reactions.
2. Addition of the scrap material changes morphology of the eutectic β-Si phase. After scrap remelting the eutectic silicon forms massive platelet-like particles. The intermetallic phases type and morphology may also vary, depending on the quality and purity of the introduced scrap. In the extreme cases it leads to formation of harmful β-Al_5FeSi phase, even if chemical composition of the alloy is in agreement with EN 1706 specification.
3. Addition of scrap material leads to significant increase of gas porosity in the alloy's microstructure. The porosity is not completely eliminated by liquid metal refining.
4. Even small differences in content of elements such iron may affect alloy microstructure. There is a need of precise control of alloy chemical composition after scrap addition. In case of increase of Fe content, elements such as Mg, Mn or Cu should be introduced to the alloy.

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