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Effect of Remelting on Microstructure of the AlSi9Cu3 Alloy with Higher Iron Content

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Abstract

Secondary or multiple remelted alloys are common materials used in foundries. For secondary (recycled) Al-Si-Cu alloys, the major problem is the increased iron presence. Iron is the most common impurity and with presence of other elements in alloy creates the intermetallic compounds, which may negatively affect the structure. The paper deals with effect of multiple remelting on the microstructure of the AlS9iCu3 alloy with increased iron content to about 1.4 wt. %. The evaluation of the microstructure is focused on the morphology of iron-base intermetallic phases in caste state, after the heat treatment (T5) and after natural aging. The occurrence of the sludge phases was also observed. From the obtained results can be concluded that the multiple remelting leads to change of chemical composition, changes in the final microstructure and also increases sludge phases formation. The use of heat treatment T5 led to a positive change of microstructure, while the effect of natural aging is beneficial only to the 3rd remelting.

Keywords: Metallography, Heat treatment, Al-Si-Cu, Remelting

1. Introduction

Secondary aluminium alloys of the Al-Si-Cu type are a material that is nowadays increasingly reinforcing its application in the production of castings for various industries. The main reason for the increasing demand for secondary alloys is economic profit. At the present time, the production of castings mainly for the automotive industry demands the costs reduction while maintaining a high quality of castings, thereby increasing overall competitiveness. When using multiple remelted material, changes of fundamental properties may occur. These changes may be depended on the number of remelting [1,2].

The main disadvantage of recycled alloys is the higher amount of iron, which has a detrimental effect on the properties of most aluminium alloys. The chemical composition of the alloy and the solidification parameters are an important factor affecting the process of intermetallic compounds, which are responsible for the resulting mechanical properties. In the absence of Si, the dominant phases that form are Al_3Fe and Al_6Fe. If Si is present, the dominant phases are Al_8Fe_2Si (α-phase) and Al_5FeSi (β-phase). Iron-based intermetallic phases reduce the tensile strength and elongation of alloys. These phases occur during solidification of the eutectic and can affect the fluidity and support the porosity formation. To reduce the adverse effect of iron, the most used chemical element is manganese, which binds iron and together forms intermetallic phases in a more acceptable form. The recommended ratio of manganese and iron to eliminate the harmful effect of iron is, according to many authors, Mn: Fe = 1: 2 [3-5].

Manganese and chromium are normally present in secondary Al alloys as impurities due to the recycling process of aluminium or can also be intentionally added to the alloy because, individually or in combination, they neutralize the effect of Fe-needle particles by modifying the morphology and type of phase. The presence of these elements has also a few disadvantages. The intermetallic compounds, for example, primary α-$Al_{15}(Fe,Mn,Cr)_3Si_2$, have a high specific gravity and tend to segregate to the bottom at the holding furnaces and form hard inclusions called sludge phases. The presence of sludge phases results in degradation of the mechanical properties.

Reducing mechanical properties to the required value can be achieved by using heat treatment. The presence of copper and magnesium in the alloys allows heat treatment by hardening. (creating of intermetallic phases of Al_2Cu and Mg_2Si, which allow a significant increase in strength characteristics).

2. Materials and experiments procedure

As the experimental material was used foundry alloy AlSi9Cu3. Chemical composition with selected elements of the alloy is listed in Table 1. To increase the iron content in the alloy was used master alloy AlFe10 for "controlled pollution" to a value of about 1.4 wt. % Fe. The resulting amount of iron intentionally exceeds allowed value (1.1 wt. %). The obtained secondary alloy was used in the next experiment process. The chemical composition of alloy with higher iron content is shown in Tab. 2.

Table 1.
Chemical composition of the AlSi9Cu3 alloy

Elem.	Si	Fe	Cu	Mn
(wt. %)	9.559	1.081	1.893	0.184
Elements	Mg	Ti	Cr	Sr
(wt. %)	0.426	0.038	0.027	<0.002

Table 2.
Chemical composition of the AlSi9Cu3 alloy after addition of Fe

Elements	Si	Fe	Cu	Mn
(wt. %)	9.347	1.416	1.741	0.178
Elements	Mg	Ti	Cr	Sr
(wt. %)	0.427	0.034	0.025	<0.002

Multiple remelting consisted of pouring ingots into prepared metal molds. After solidification and cooling, these ingots were used as a batch for further melting without additional components addition. This process was repeated 6 times. For structural analysis were cast samples from the first melt (D1 as the reference sample) and from each second melt (D3, D5, D7) into a metal mold with a minimum temperature of 100 ± 5 °C. Melting process was carried out in an electric resistance furnace and the casting temperature was in the range of 750 to 770 °C. The melt was not further modified, grain refined or purified. Before pouring, only oxide films on the surface of the melt were removed.

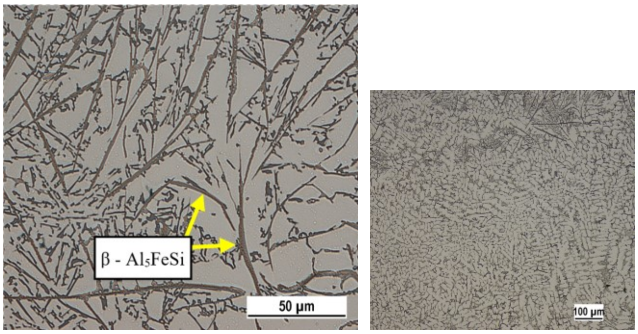
3. Results

3.1. Microstructure

Experimental samples were prepared for microstructural evaluation by the standard metallographic procedure. The samples were then divided into three groups. The first group consisted of samples that were evaluated, in a casted state i.e. when no heat treatment was performed. The second group consisted of samples that were subjected to structural analysis after naturally aging (about 160 hours at 20 °C). The third group was composed of samples after heat treatment (T5 - artificially aging at 200 ± 5 °C for 4 hours and cooling in water).

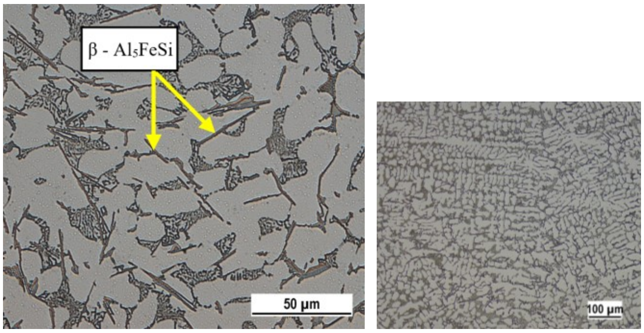
Casted state

The microstructure of D1 alloy (reference alloy Fig. 1) consists of α-phase dendrites, eutectic silicon in the form of imperfectly rounded grains, iron based intermetallic phases mainly in form of Al_5FeSi phase "needles". On the D3 alloy microstructure (Fig. 2), it can be seen that the fundamental change after the 3rd remelting occurred by the shortening needles of the iron phase and in refinement of the eutectic silicon. After the 5th remelting, the shape of the eutectic silicon changed from modified morphology to grainy morphology (Fig. 3). Due to increased number of remelting the number and size of iron phases increased as well, and the eutectic silicon crystallized in the "unmodified form" (Fig. 4).



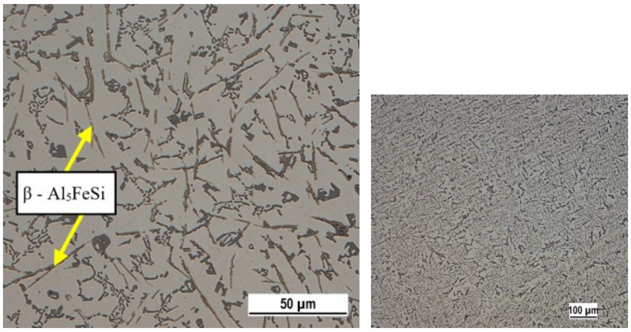
a) b)

Fig. 1. Optical micrographs showing microstructure of 1st AlSi9Cu3 alloy cast (D1) in cast state:
a) magnification 500x b) magnification 100x



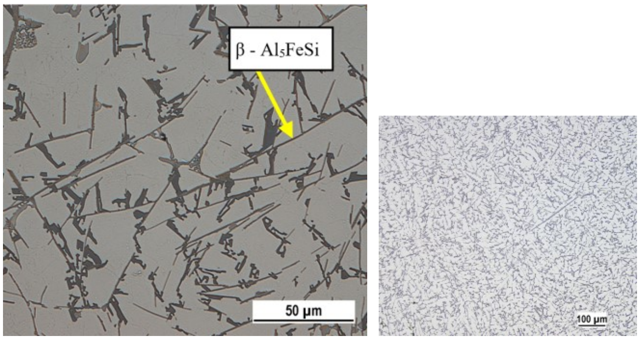
a) b)

Fig. 2. Optical micrographs showing microstructure of 3rd AlSi9Cu3 alloy cast (D3) in cast state:
a) magnification 500x b) magnification 100x



a) b)

Fig. 3. Optical micrographs showing microstructure of 5th AlSi9Cu3 alloy cast (D5) in cast state:
a) magnification 500x b) magnification 100x

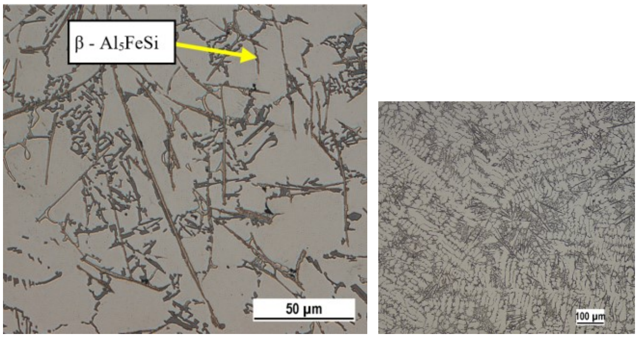


a) b)

Fig. 4. Optical micrographs showing microstructure of 7th AlSi9Cu3 alloy cast (D7) in cast state:
a) magnification 500x b) magnification 100x

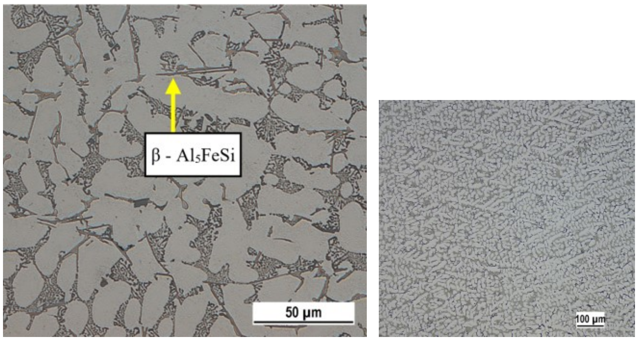
Artificially aged (T5)

On the microstructures (Fig. 5 to 8) it can be seen that influence of heat treatment changed shape of the eutectic silicon. Significant rounding (spheroidization) occurred especially in alloys D3 (Fig. 6) and D5 (Fig. 7), where the eutectic silicon is in a modified form i.e. in the form of short isolated spherical particles, which are seen in facet as a round grain. In the alloy D7 (Fig. 8), there was no complete spherodiziation of eutectic silicon as with alloys with a lower number of melting. The morphology of the iron phases present in the alloy was not affected, but the visible change occurred in dimensions. Excluded iron phases have been shortened and may be observed a slight refinement of the iron phases.



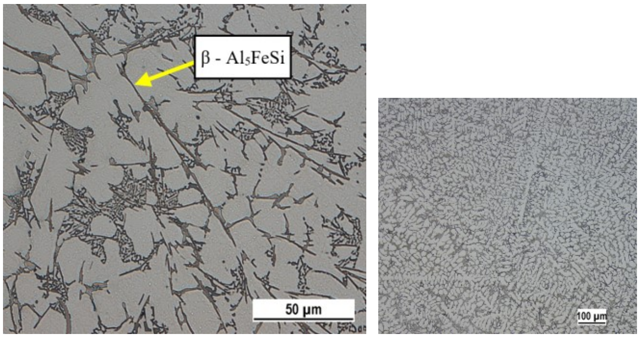
a) b)

Fig. 5. Optical micrographs showing microstructure of 1st AlSi9Cu3 alloy cast (D1) after Artificially aged:
a) magnification 500x b) magnification 100x



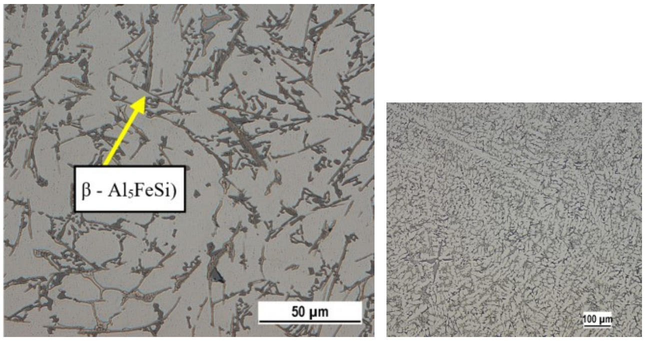
a) b)

Fig. 6. Optical micrographs showing microstructure of 3rd AlSi9Cu3 alloy cast (D3) after Artificially aged:
a) magnification 500x b) magnification 100x



a) b)

Fig. 7. Optical micrographs showing microstructure of 5th AlSi9Cu3 alloy cast (D5) after Artificially aged:
a) magnification 500x b) magnification 100x

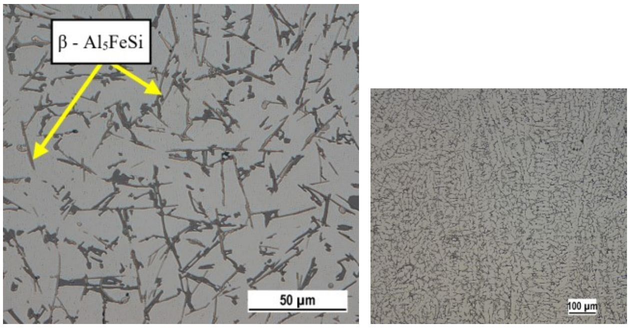


a) b)

Fig. 8. Optical micrographs showing microstructure of 7th AlSi9Cu3 alloy cast (D7) after Artificially aged: a) magnification 500x b) magnification 100x

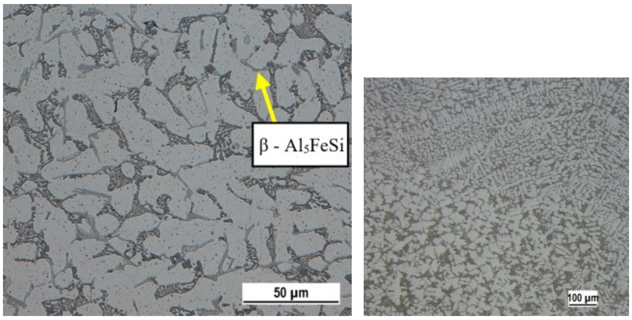
Naturally aged

The effect of natural aging on the structure of alloys is shown in Fig. 9 to 12. As with the heat treatment of T5, the effect of natural aging on the eutectic silicon morphology is noticeable, especially in alloys with higher numbers of remelting. For alloys D1 (Fig. 9) and D3 (Fig. 10), can be observed shortening of iron phases needles length compared to the casted state. The structure of alloys after the 5th and 7th remelting is also after natural aging characterized by long thin needles of iron-based phases.



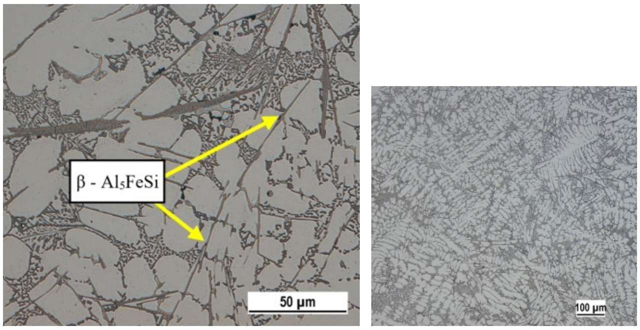
a) b)

Fig. 9. Optical micrographs showing microstructure of 1st AlSi9Cu3 alloy cast (D1) after Naturally aged: a) magnification 500x b) magnification 100x



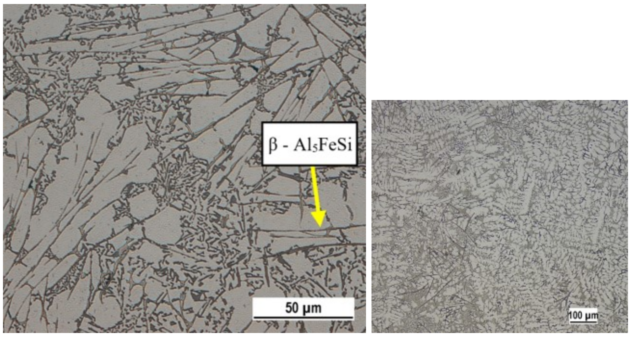
a) b)

Fig. 10. Optical micrographs showing microstructure of 3rd AlSi9Cu3 alloy cast (D3) after Naturally aged: a) magnification 500x b) magnification 100x



a) b)

Fig. 11. Optical micrographs showing microstructure of 5th AlSi9Cu3 alloy cast (D5) after Naturally aged: a) magnification 500x b) magnification 100x



a) b)

Fig. 12. Optical micrographs showing microstructure of 7th AlSi9Cu3 alloy cast (D7) after Naturally aged: a) magnification 500x b) magnification 100x

Another important parameter in the evaluated Al-Si alloys is the ratio of Mn and Fe. The addition of manganese is most often recommended in an amount of at least half the iron content (Mn/Fe ≥ 0.5). In Tab. 3 is given by wt. % manganese and iron depending on the number of remelting. This ratio was lower than the recommended value in each alloy (Fig. 13), there is a high probability of iron phase exclusion in the negative needles form, which has also been confirmed by microstructure observation.

Table 3.
Relationship between wt. % Mn and Fe and cast number (CN)

CN	D1	D2	D3	D4	D5	D6	D7
Mn	0.178	0.176	0.186	0.221	0.181	0.196	0.187
Fe	1.416	1.475	1.51	1.705	1.738	1.809	1.889

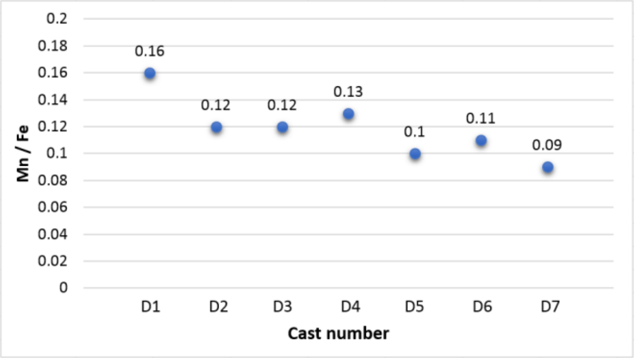


Fig. 13. Relationship between ratio Mn/Fe and cast number

As a result of remelting, the iron (Tab. 3) and the chromium concentration (Tab. 4) in the alloy increases. This increase may lead to occurrence of so called "sludge phases". Amount of these particles depend mainly on the concentration of iron, chromium, and manganese, expressed by sludge factor SF (1):

$$SF = [\%\,Fe] + 2 \cdot [\%\,Mn] + 3 \cdot [\%\,Cr] \qquad (1)$$

The results of the sludge factor equation (1) depending on the number of remelting are shown in Tab. 5.

Table 4.
Relationship between wt. % Cr and Fe and cast number (CN)

CN	D1	D2	D3	D4	D5	D6	D7
Cr	0.025	0.027	0.04	0.046	0.065	0.093	0.106

Table 5.
Relationship between sludge factor (SF) and cast number (CN)

CN	D1	D2	D3	D4	D5	D6	D7
SF	1.847	1.91	2.002	2.285	2.295	2.48	2.89

Gobrecht and Jorstad [8] found an empirical relationship which can be applied to several Al-Si-Cu alloys. The relationship expresses the dependence between the sludge factor and the minimum holding temperature, under which the alloy tends to form sludge phases. Fig. 14 illustrates graphically obtained approximate values of minimum holding temperatures for individual melts. The resulting values were obtained on the basis of the relationship between the sludge factor and the temperature. Also, from Fig. 14, it can be seen that the effect of remelting increases the minimum holding temperature from 640 ± 5 °C to approximately 700 ± 5 °C.

The increase in the holding temperature indicates that the effect of the remelting also increases the probability of the sludge phases in the melt using the same holding temperature for all alloys. This assumption was confirmed for the alloy in casted state after 5th and 7th remelting (Fig. 15 and Fig. 16). In the microstructure, the presence of sludge phases can be seen.

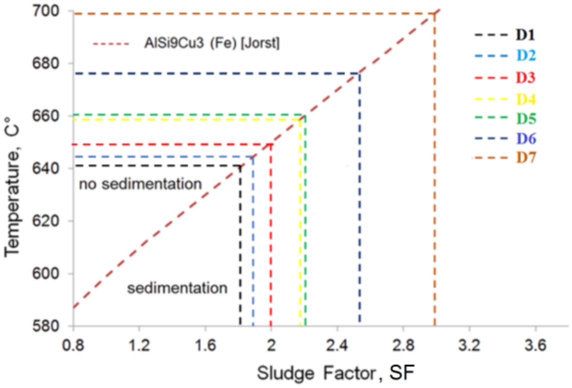


Fig. 14. Values of minimum holding temperatures of alloys D1 to D7 derived from relationship between sludge factor SF and temperature

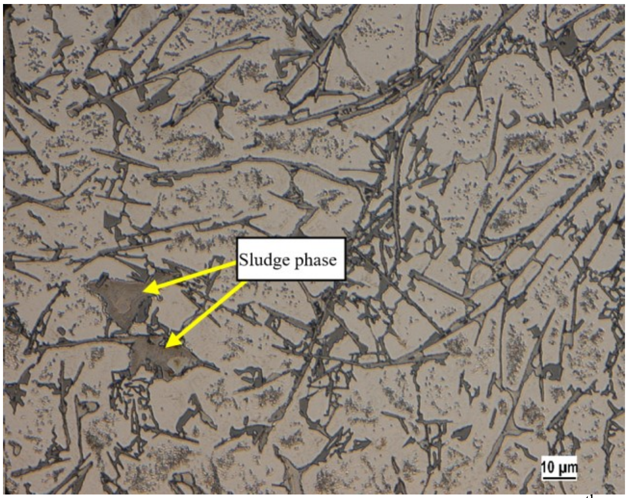


Fig. 15. Optical micrographs showing microstructure of 5th AlSi9Cu3 alloy cast (D5) in cast state, magnification 800x

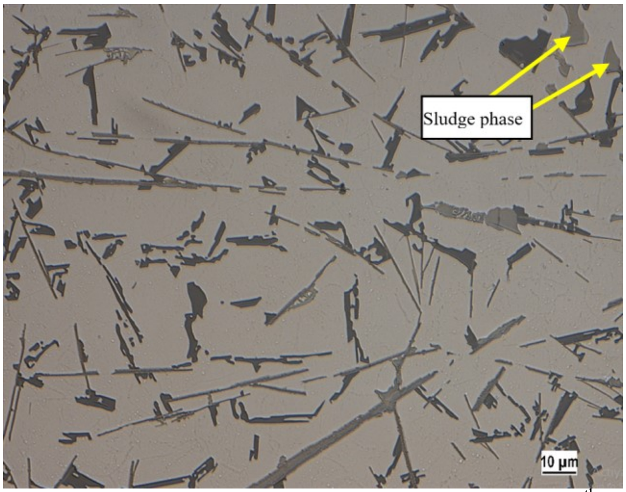


Fig. 16. Optical micrographs showing microstructure of 7th AlSi9Cu3 alloy cast (D7) in cast state, magnification 800x

5. Conclusions

The increasing number of remelting for AlSi9Cu3 alloy with higher iron content has confirmed a negative effect on the microstructure. Although the best structure was shown in the sample after the 3rd remelting (alloy D3 - modified morphology), when occurred globalization of eutectic silicon and shortening needles of the iron phases. With the increasing number of remelting, a negative effect has begun to cause an increase in the number and size of the iron phases. An equally negative effect was also seen with eutectic silicon, which was formed in the undesirable form of thin needles (unmodified morphology).

The use of the heat treatment T5 led to a positive effect on the microstructure. Due to heat treatment, eutectic silicon was spheroidized and the iron-based phases shortened on all four alloys. It can be concluded that heat treatment affected the size of the iron phases.

Naturally aging also had a positive effect on the change of eutectic silicon (spheroidization), but only D1 and D3 alloys have been altered to change the shape of the iron-based phases. For D5 and D7 alloys, naturally aging had no significant effect on the shape of the iron-based phases, which were excluded in the form of long needles.

From the obtained results, it can be stated that remelting negatively affects the resulting microstructure and with increasing number of remelting is necessary to increase the holding temperature due to the increased probability of sludge phase formation. Heat treatment T5 has proven to be a more appropriate way to reduce the negative influence of remelting as naturally aging.

References

[1] Bolibruchová, D., Macko, J. & Brůna, M. (2014). Elimination of negative effect of Fe in secondary alloys AlSi6Cu4 (EN AC 45 000, A 319) by nickel. *Archives of Metallurgy and Materials.* 59(2), 717-721. DOI: 10.2478/amm-2014-0118.

[2] Krivoš, E., Pastirčák, R. & Madaj, (2014). Effect of technological parameters on the quality and dimensional accuracy of castings manufactured by patternless process technology. *Archives of Metallurgy and Materials*. 59(3), 1069-1072. DOI: 10.2478/amm-2014-0182.

[3] Taylor, J.A. (2012). Iron-containing intermetallic phases in Al-Si based casting alloys. *Procedia Materials Science.* 1, 19-33. DOI: 10.1016/j.mspro.2012.06.004.

[4] Cao, X. & Campbell, J. (2006). Morphology of Al_5FeSi Phase in Al-Si Cast Alloys. *Materials Transactions*. 47(5), 1303-1312. DOI: 10.2320/matertrans.47.1303.

[5] Elsharkawi, E.A., et al. (2010). Effects of Mg, Fe, Be additions and solutions heat treatment on the π-AlMgFeSi iron intermetallic phase in Al-7Si-Mg alloys. *Journal of Materials Science*. 45, 1528-1539. DOI: 10.1007/s10853-009-4118-z.

[6] Shabestari, S.G. et al. (2002). Effect of Mn and Sr on intermetallics in Fe-rich eutectic Al-Si alloy. *International Journal of Cast Metals Research.* 15, 17-24. DOI: 10.1080/13640461.2002.11819459.

[7] Zhang, Z., et. al. (2013). Effect of the Mn/Fe ratio and cooling rate on the modification of Fe intermetallic compounds in cast A356 based alloy with different Fe contents. *Materials Transactions.* 54 (8), 1484-1490. DOI: 10.2320/matertrans.F-M2013808.

[8] Ferraro, S., Bjurenstedt, A. & Seifrddine, S. (2015). On the formation of Sludge intermetallic particles in secondary aluminium alloys. *Metallurgical and Materials Transactions A*. 46(8), 3713-3722. DOI: 10.1007/s11661-015-2942-0.