Semi-continuous casting and microstructure investigation of the AlSi12 alloy

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Abstract. Semi-continuously cast AlSi12 alloy was investigated by our research group at the University of Miskolc in the Institute of Physical Metallurgy, Metalforming and Nanotechnology under laboratory condition. Our goal was to define correlation and tendency between casting parameters and solidified microstructures. The examined alloy is used as filler material, thus cover soldering technology and exchangers are made from it, like car coolers, radiators, air conditioners. During the investigation optical microscope was used for sight of ingot microstructure, secondary dendrite arm spacing was measured in this way and even the amount of primary α-phase.

1. Introduction
Aluminium and its alloys are often applied as industrial commodity in many ways. Besides high strength conventionally as cast Al alloys with more alloying elements (for examples AlSi, AlMg, AlSiCu, AlZnMg) and lower strength wrought Al alloys with less alloying elements (for examples AlMgMn, AlMn, AlMgZn) aluminium is used as a filler material because of its low melting point and sufficient strength for consumption with several amount of Si, perhaps with other micro alloying elements too [1, 2]. The technology conditions of casting greatly influence the solidifying microstructure [3]. At the University of Miskolc in the AluForm project our group carried out semi-continuous castings of different alloys by Indutherm CC3000 equipment [4]. AlSi12 was produced by this way in a laboratory at small size, which alloy is applied for making cooler/heater systems by soldering technology in the industry at large size [5]. The aim of the research was in order to observe the casting parameters for the solidifying microstructure. These kind of parameters are the secondary water-cooling and the casting speed, which is combined by the pulling speed and the pause function during the process. Microstructure directly influences attribution of the material [6, 7], that plays significant role in the working up of the raw material and usage of the end product. Primary solid solution is a soft texture element in the alloy, so it can be formed easily. Its shape is a branching dendrite and it has got primary and secondary arms. The secondary dendrite arm spacing (sDAS) defines the refinement of the microstructure. The smaller this distance, the greater the strength of the material. At higher solidification rate smaller dendrite arm spacing comes into being [8]. From the usage perspective the most appropriate microstructure of the AlSi12 alloy is homogeneous, formable with the soldered alloy together and melts easily in the furnace.
2. The AlSi alloy

Aluminium constitutes eutectic system with silicon as shown in Fig. 1. The eutectic temperature is 577°C, and the eutectic point is at 11-13% of silicon content. As the silicon content changes in the alloy several phases form in case of equilibrium solidification process, which are introduced below:

(a) From 0% to 1.65% Si content: From the molten metal primary α-solid solution solidifies, then under the solvus temperature β-silicon precipitates.
(b) From 1.65% to 11-13% Si content (hypoeutectic alloy): After the solidification of dendrite shaped primary α-solid solution, eutectic α+β phases solidify from the remainder melt.
(c) 11-13% of Si content (eutectic alloy): In this case eutectic is created if it is an absolutely equilibrium solidification. In practice it contains other texture elements.
(d) More, than 11-13% of Si content (hypereutectic alloy): Firstly primary silicon solidifies, then eutectic comes to be from the remainder melt. The primary silicon occurs with different Si contents in the texture if the solidification is not equilibrium.

This is not advantageous for working the raw material up because of its rigidity. It can be refined by phosphorus in melt condition [10].

2.1. AlSi alloy, as a filler

As a filler AlSi can be used between different type of materials to bind, like Al-Al, TiAl-TiAl, Al-steel and even ceramics to make bond [1, 2, 11, 12]. The most often used alloy is the AlSi12 melting at the lowest temperature and it has enough good viscosity. These criterions are needed so that Al fills strait gaps during soldering, but higher Si content can induce porosity in the bond, which influences strength to negative line [5].

Sheets are got with each other during covering solder technology, so that filler raw material is between the sheets and these are rolled. After this process rolled sheets get heat treatment in a furnace, the filler (solder) melts and fills gaps [5].

3. Experiments

Semi-continuous casting means casting of the molten metal into a water-cooled die solidifying an ingot, which is pulled out from the die by rolls [4]. Limited ingot length is produced by this method, its cross-section size is from few centimeters even to some meters, which geometry is circular or square. The cast ingot is a raw material for rolling, extruding and forging technologies.

Casting equipment is shown in Fig. 2., which was applied for the AlSi12 alloy casting. Its chemical composition is 12.7% Si, 0.2% Fe and 0.1% > Mg, Mn, Cu, which are weight percents. Principle of operation of the equipment had been introduced in another paper [4]. Cross-section was 10 x 100 mm and 3-3 pieces of samples were taken from every section, where centre and edge parts were investigated. These are shown in Fig. 3-4. In all 5 pieces of experiments were done and one piece of casting parameter was changed in each case. We mark these in Table 1. Comparisons were made in pairs illustrated by colours: secondary cooling by blue, casting speed without secondary cooling by green and pause with secondary cooling during casting by orange. Parameters were chosen taking into account of ability the technological solidification of AlSi12 alloy. During the casting process the speed of solidification frontline depends on the casting speed through the mushy zone (contains liquid and solid phases) geometry [3]. As mushy zone is getting deeper, the higher difference of rate of solidification velocity is between edge and centre of the ingot. Depth of the zone depends on the heat energy quantity of the sys-
Quantity of energy increases when casting speed is lower and secondary water-cooling is not used. In case of higher solidification rate secondary dendrite arm spacing will be smaller, so causes finer microstructure. The amount of α-solid solution depends on local concentrations during solidification also in contact with the rate of solidification.

3.1. Measurements
Microstructure and homogeneity of the polished and Barker etched samples were investigated by optical microscope in 50x magnitude without polarized light.

![Figure 2. The Induterm CC3000 equipment](image)

![Table 1. Casting parameters](table)

### Table 1. Casting parameters

| #Experimental matrix | T<sub>melt</sub> (°C) | T<sub>die</sub> (°C) | v<sub>pulling</sub> (mm/s) | Pulling pause (s) | V<sub>casting</sub> (mm/s) | Secondary cooling |
|----------------------|----------------------|----------------------|--------------------------|------------------|--------------------------|------------------|
| #1                   | 750                  | 450                  | 0.1                      | 0.1              | 0.091                    | Not used         |
| #2                   | 770                  | 450                  | 0.1                      | 0.1              | 0.091                    | Used             |
| #3                   | 770                  | 450                  | 0.3                      | 3.0              | 0.075                    | Not used         |
| #4                   | 740                  | 450                  | 4.0                      | 0.0              | 4.000                    | Used             |
| #5                   | 770                  | 450                  | 4.0                      | 9.9              | 0.370                    | Used             |

![Figure 3. Size of the ingot and pulling direction of the samples](image)

3.1.1. Secondary dendrite arm spacing. Secondary dendrite arm spacing is measured from centres of two arms, then the encased length was divided with the number of “taken arms-1”, shown in Fig. 5. The resulted number is the average sDAS. In case of AlSi alloy primary α-solid solution phase solidifies from the melt getting dendrite structure and gives the refinement of its microstructure (Fig. 6.).

\[ sDAS = \frac{L}{P-1} (\mu m) \]

where L – measured distance between two secondary arms (μm), P – numbers of arms (-).
to measure and we calculated the amount of it \( A \).

\[
A = \frac{A_\alpha}{A_{all}} \times 100 \%
\]

where \( A_\alpha \) – the area of primary phase (\( \mu m^2 \)) and \( A_{all} \) – the all area of the image (\( \mu m^2 \)).

**4. Results**

**4.1. Microstructure**

Barker electrolytic etched microstructures of samples of experiments (5 pieces) were investigated from different positions through cross-section of the ingots. In this paper just centre structures of all experiments are introduced in Fig. 8. in 50 mm sample position along the ingot width (Fig. 3-4.).

In case of same casting speed without using secondary cooling microstructure is more disperse in the edge part of the ingot. Structure of the centres have not changed (Fig. 8. a and b). With using secondary cooling in case of lower casing speed homogeneous and fine microstructure has been reached in both of edge and centre. Ordered dendrite structure has disappeared. These are shown in Fig. 8. a) and c). During the casting process using of pause function can be more advantageous for the solidifying microstructure. Its result is an unified and ordered microstructure through the cross-section (Fig. 8. d and e). As number \#3 experience presented, lower casing rate (0.075 mm/s) with no secondary cooling (assuming it had

**3.1.2. Picture analysis**. Black and white images were taken about microstructure with microscope in the right magnitude. After reading into Leica QWin software calibration was done through scale bar in order to define how many pixels mean a micrometer. In the next steps dark parts of images were detected and the level of the gray-shade were given from 0 to 255 (\( \mu m \)), which exactly determines the dark phases (Si) according to the given image, thus in this way new, binary pictures were generated. Morphological binary picture transformations were accomplished on all binary pictures like: by 5 cycles of closing in the eutectic light coloured secondary \( \alpha \)-phase was also detected. 5 cycles of closing means consecutive of 5 steps of dilatation and erosion. Dilatation means increasing the edge of the detected object with 1 pixel in every direction, furthermore erosion means decreasing of its edge. Inverting of the detection the area of the primary \( \alpha \)-phase \( (A_\alpha) \) was immediately able to measure and we calculated the amount of it \( (A_\alpha) \). \( A_\alpha = \frac{A_\alpha \times 100}{A_{all}} \) (%) where \( A_\alpha \) – the area of primary phase (\( \mu m^2 \)) and \( A_{all} \) – the all area of the image (\( \mu m^2 \)).

![Figure 5](image5.png)  **Figure 5.** Measurement of the sDAS [13]

![Figure 6](image6.png)  **Figure 6.** Measurement of the sDAS in case of practice, HF etching, magnification: 200x

![Figure 7](image7.png)  **Figure 7.** Process of the picture analysis for measuring the amount of primary \( \alpha \) – phase area
the lowest solidification rate) has resulted the most homogeneous microstructure. As number #5 experience displayed, casting speed can be increased if secondary cooling is used for a good result. Using this method casting process can be accelerated getting advantage for the industry.

![Microstructures of the cast ingots from 50 mm sample position along the ingot width with different casting parameters (#1 - #5), Barker etching without polarized light, magnification: 50x, a) Without secondary cooling, $v_{\text{casting}}$: 0.091 mm/s (#1), b) With secondary cooling, $v_{\text{casting}}$: 0.091 mm/s (#2), c) Without secondary cooling, $v_{\text{casting}}$: 0.075 mm/s (#3), d) With secondary cooling, $v_{\text{casting}}$: 4 mm/s (#4), e) With secondary cooling, $v_{\text{casting}}$: 0.37 mm/s (#5)](image)

4.2. Results of secondary dendrite arm spacing of cast ingots

Results of sDAS measurement are shown in Fig. 9. Secondary cooling has had positive effect.

In the edge sDAS has decreased uniformly from 15-35 μm to 15-16 μm (Fig. 9. a and b). sDAS of the centre part has not changed using secondary cooling, it is 13-15 μm. This is due to the cooling, because of the depth of mushy zone has decreased in the ingot during casting process. In the edge the rate of solidification velocity has increased. At lower casting speed (0.075 mm/s) sDAS is uniformly 13-15 μm through the cross-section of the ingot as shown in Fig. 9. a) and c). The depth of mushy zone has decreased, and same solidification rate is assumed in both of edge and centre. Using the pause function during casting has not had significant effect to sDAS, it is 10-23 μm (Fig. 9. d and e).
Figure 9. Secondary dendrite arm spacing (sDAS) of the cast ingots with different casting parameters (#1 - #5): a) Without secondary cooling, \( v_{\text{casting}} \): 0.091 mm/s (#1), b) With secondary cooling, \( v_{\text{casting}} \): 0.091 mm/s (#2), c) Without secondary cooling, \( v_{\text{casting}} \): 0.075 mm/s (#3), d) With secondary cooling, \( v_{\text{casting}} \): 4 mm/s (#4), e) With secondary cooling, \( v_{\text{casting}} \): 0.37 mm/s (#5)

4.3. Average area amount of the primary \( \alpha \)-solid solution

In the solidified microstructure the calculated amount of primary solid solution has shown in Fig. 10. With secondary cooling the amount of \( \alpha \)-phase has decreased from 23-33% to 19-22% in the edge approaching 18% like in the centre, which has not changed. Results are shown in Fig. 10. a) and b). At lower casting speed (0.075 mm/s) the area amount of \( \alpha \)-phase has decreased in the edge, so uniformly is has been 20% through cross-section of the ingot (Fig. 10. a and c). Using the pause function during casting (0.37 mm/s) the amount of \( \alpha \)-phase has decreased to 17-18% in the centre, which is same value to the edge’s (Fig. 10. d and e).
5. Conclusions
The aim of our research was to investigate microstructure of semi-continuous cast AlSi12 alloy affected by changing casting parameters, like rate of casting speed and using of secondary cooling.

Due to our results we take the following statements:

(a) Secondary water-cooling has significant and advantageous effect to the solidified microstructure, because using it the cooling rate is intensive, thus structure becomes refined and homogeneous. In this case secondary dendrite arm spacing is 15 μm also in the edge part of the ingot, the amount of α-phase has decreased 12%.

(b) Decreasing the casting speed (0.075 mm/s) homogeneous dispersion of sDAS has formed in the microstructure through the cross-section (13-15 μm). The amount of α-phase has decreased from 23-33% to 20%.
During the casting process using the pause function has great effect to the solidification of microstructure. Across the cross-section of AlSi12 ingot solidification rate becomes equal due to the less depth of mushy zone [3], so microstructure solidifies homogenously. Consequently stated how homogeneous microstructure can be reachable: in case of lower casting speed (0.075 mm/s) without using secondary cooling or in case of greater casting speed (0.37 mm/s) using secondary cooling.

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