# Influence of Strip Thickness on As-Cast Material Properties of Twin-Roll Cast Aluminum Alloys

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**Abstract**

Microstructural features of twin-roll cast aluminum products are strongly affected by the parameters of the casting process. Among these parameters, strip thickness is one of the most critical ones which dictates the solidification process and directly affects the microstructure and the quality of the as-cast sheet surface. In this study, 8xxx (Al-Fe-Mn) alloys were cast with different strip thicknesses via an industrial scale twin-roll caster and it was aimed to elucidate the effect of the strip thickness on secondary phases and grain structures along with the formation of macro-segregations. Microstructures of the samples were investigated by employing metallographic techniques. Complementary studies were performed by tensile tests, electrical conductivity and micro hardness measurements. Results show that the strip thickness is an important tool to obtain desired properties in as-cast materials.

**Keywords**

Twin-roll casting • Strip thickness • As-cast microstructure

## Introduction

Twin-roll casting (TRC) is a proven technology for producing aluminum sheets and foils. In TRC, solidification of liquid metal is followed by hot deformation and it is very crucial to control various process parameters such as melt temperature, casting speed, setback and strip thickness. The combination of the effects of these parameters plays an important role on solidification behavior of the liquid metal and dictates the microstructural features of the as-cast materials [1]. The change in the temperature gradient encountered through thickness of the solidifying metal results in heterogeneities in intermetallic particle sizes and distributions and leads to formation of macro-segregations, especially the centerline segregations (CLS). The CLS in TRC is due to the segregation of solute elements, which are swept to the center of the sheet by the two opposite solid/liquid interfaces [2]. CLS formation is due to relatively low separating force exerted on the caster rolls, which results in low heat extraction from liquid metal to the rolls and can be eliminated by increasing the separating force [3]. These segregations are in different forms such as channel segregates, deformation segregates and banded structures. There are limit diagrams in literature showing the correlation of these structures with the separating force and the strip thickness. As the strip thickness is altered, the geometry of the roll bite, the temperature gradient and the separating force exerted on the rolls change which in turn influence the microstructural features of as-cast materials such as intermetallic particle sizes/distributions, grain sizes and segregation formations [1, 4].

In this respect, 8xxx (Al-Fe-Mn) alloys were cast with different strip thicknesses in order to investigate the effect of strip thickness on the microstructural features of as-cast sheets.

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## Experimental Studies

In this study, 8xxx aluminum alloys were cast with different strip thicknesses, which are 6, 5, 4 and 3 mm respectively, via an industrial scale twin-roll caster in order to investigate the effect of the strip thickness on microstructure. The reduction in the strip thickness was obtained by decreasing the roll gap and the setback while increasing the casting speed. The headbox and the cooling water temperatures were also altered to achieve the desired thicknesses. Samples were taken for metallographic investigations and marked as Sample A, Sample B, Sample C and Sample D. The chemical composition, the sample codes and the separating forces exerted on the rolls are given in Tables 1 and 2, respectively. Samples were also homogenized at 540 °C in order to examine the evolution of the microstructure. Metallographic investigations were conducted both by examining the cross-sections and the surfaces of the samples with an optical microscope. Complementary studies were carried out by tensile tests and micro-hardness tests prior to homogenization. Electrical conductivity (EC) measurements were conducted at room temperature on both as-cast and homogenized samples at 60 kHz.

## Results and Discussion

EC measurement results of as-cast and homogenized samples are shown in Table 3. Electrical conductivities of as-cast samples are similar although Sample D exhibits a slightly lower conductivity, which is 21.8 mS/m. This can be a result of a higher supersaturated matrix, which can be attributed to the higher separating force exerted on the rolls during solidification. As the separating force increases, more heat is extracted from the liquid metal by the rolls so that cooling rate can increase. Increased cooling rate enhances the saturation of the material by capturing more solute elements in the matrix. Homogenization heat treatment leads to increase the conductivities of all samples, which is due to the precipitation of Mn-bearing particles and reduced concentration of manganese in the solid solution. Studies have shown that manganese can concurrently precipitate during heat treatments, which on the other hand influences the texture evolution and the recrystallization behavior of the aluminum alloys [5, 6]. The rate of increase in EC is highest for Sample D, which indicates its higher potential to make precipitates due to the highest saturation level at the initial stage.

Tensile test results (Table 4) reveal that as the strip thickness decreases, yield and tensile strengths of the samples increase. The increase in strengths are modest as the thickness changes from 6 to 4 mm, whereas Sample D exhibits a significant increase in strength when compared to other samples. This increase in strength can again be associated with its higher separating force and predicted cooling rate. Strengths measured along casting direction are higher with respect to that of measured perpendicular to the casting direction for all strip thicknesses.

Micro-hardness measurements, shown in Fig. 1, support the findings deduced from tensile test results. Sample D, which is 3 mm thick, possesses the highest micro-hardness values especially at the outermost surface layer and the quarter of the thickness of the sample. Samples B and C have similar micro-hardness values, whereas Sample A exhibits the lowest hardness values as it was observed in tensile test results.

Figure 2 depicts the size and the distribution of the secondary phases through the cross-section of the samples. Due to the cooling gradient encountered in TRC materials, the size and the distribution of the secondary phases change through the cross-section. Intermetallic particles at the outermost layers are very fine and closely distributed whereas, particle sizes gradually increase as they get closer to the center-plane of the material. At the center, there are coarse eutectic phases enriched in solute elements [7]. Intermetallic particles at the surface of Sample A and Sample B are similar. However, the number of intermetallic phases increase as the strip thickness goes to 4 and 3 mm,

**Table 1** Chemical composition

| Element, wt % | | | | |
|---|---|---|---|---|
| Si | Fe | Mn | Zn | Ti |
| 0.15 | 1.43 | 0.64 | 0.02 | 0.01 |

**Table 2** Sample codes

| Sample | Strip thickness, mm | Separating force, t |
|---|---|---|
| A | 6 | 1430 |
| B | 5 | 1490 |
| C | 4 | 1780 |
| D | 3 | 2310 |

**Table 3** Electrical conductivities of as-cast and homogenized samples

| Sample | Condition | Electrical conductivity (EC), mS/m | Increase in EC, % |
|---|---|---|---|
| A | As-cast | 22 | 35.4 |
| | Homogenized | 29.8 | |
| B | As-cast | 22 | 34.5 |
| | Homogenized | 29.6 | |
| C | As-cast | 22 | 34.5 |
| | Homogenized | 29.6 | |
| D | As-cast | 21.8 | 35.8 |
| | Homogenized | 29.6 | |

**Table 4** Tensile test results of as-cast samples

| Sample | Test direction | Yield strength MPa, | Tensile strength, MPa | Elongation, % |
|---|---|---|---|---|
| A | 0 | 112 | 165 | 12.8 |
| | 90 | 111 | 157 | 9.8 |
| B | 0 | 114 | 169 | 15.2 |
| | 90 | 111 | 159 | 16.7 |
| C | 0 | 119 | 170 | 13.8 |
| | 90 | 115 | 162 | 12.8 |
| D | 0 | 135 | 185 | 18.7 |
| | 90 | 130 | 180 | 11.9 |

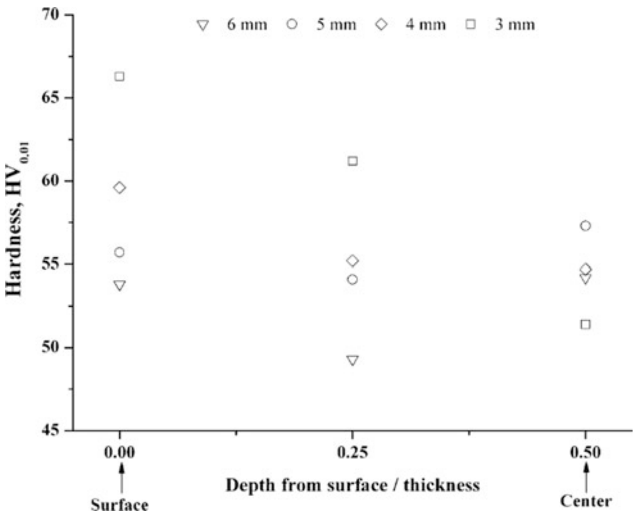

**Fig. 1** Micro-hardness measurements of as-cast samples

respectively. When the quarter-planes of the samples are examined, a similar result can be deduced. Intermetallic phases of Sample A and Sample B are connected to each other in a network whereas, the network structure starts to break in Sample C and they reveal themselves as individual particles in Sample D. The CLS of Sample D is more compact and different from those of other samples. As the strip thickness becomes thicker, the CLS get branched and looser.

The secondary phases on the surface are shown in Fig. 3. Eutectic-like structures are observed at both surfaces of Sample A and Sample B and a network structure of intermetallic particles is observed as it was in the case of the quarter-plane investigations. However, intermetallic phases get smaller and individual as the strip thickness decrease. Additionally, Sample D exhibits accumulations of intermetallic particles, which leads to depleted zones at the top surface. Among all the samples, Sample C has the most homogeneous distribution of intermetallic particles.

The grain structures before and after homogenization are shown in Fig. 4. TRC materials exhibit a featureless zone at the outermost layers and a deformed grain structure along casting direction just beneath this featureless zone due to the hot deformation, which solidified metal undergoes just after the solidification. At the center, the grains become larger and quasi-equiaxed. Micrographs show that as the strip thickness decreases, the grains get smaller and more deformed along the casting direction. Sample A and Sample B have similar grain structures while deformation is more pronounced in Sample D. Homogenization performed at 540 °C modifies the microstructures by altering the size and the distribution of the grains through cross-sections. Deformed grains at quarter-planes, which are observed at as-cast state, change their shape into new quasi-equiaxed grains by grain growth mechanisms. This phenomenon is easier to observe especially in Sample D.

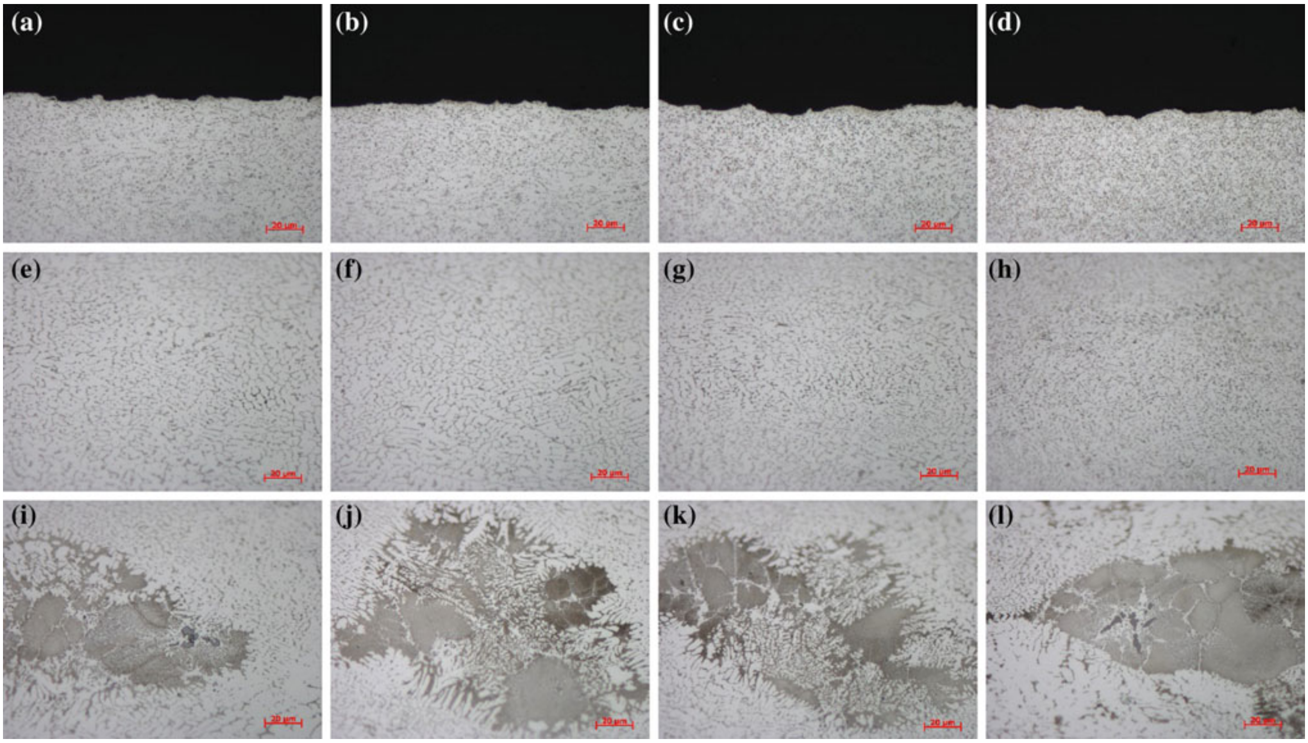

**Fig. 2** Secondary phases of as-cast sample cross-sections, **a**–**d** outermost layers—6, 5, 4, 3 mm respectively, **e**–**h** quarter planes—6, 5, 4, 3 mm respectively, **i**–**l** center planes—6, 5, 4, 3 mm respectively

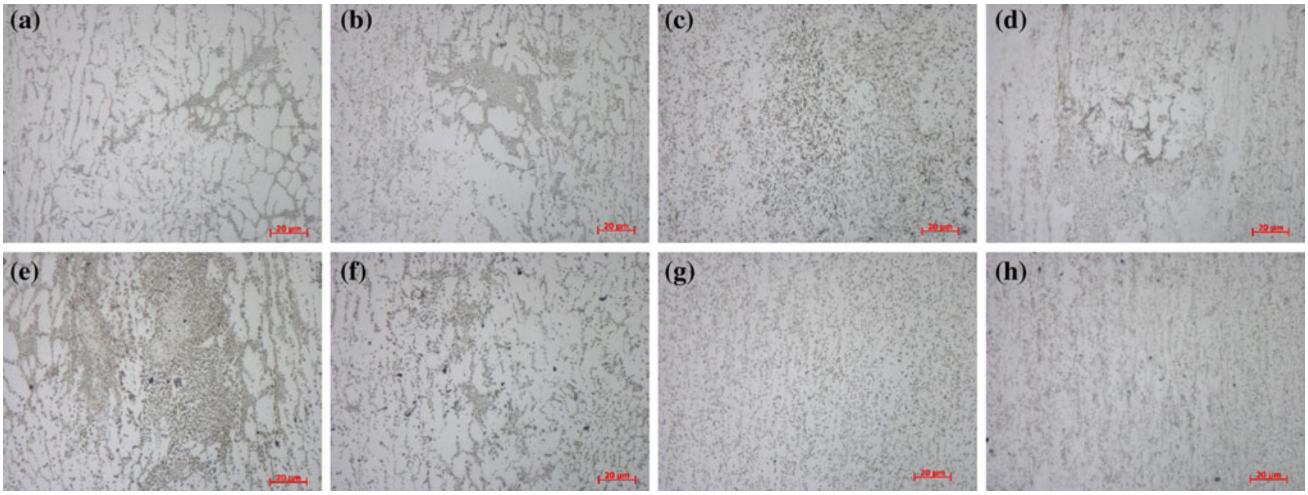

**Fig. 3** Secondary phases of as-cast sample surfaces, **a**–**d** top surfaces—6, 5, 4, 3 mm respectively, **e**–**h** bottom surfaces—6, 5, 4, 3 mm respectively

Along with this, the outermost layers of the samples show abnormal grain growth except Sample A having 6 mm strip thickness. With decrease in strip thickness, the area, which is occupied by abnormally large grains, expands through the center-plane of the samples. Sample C and Sample D have thicker grains with respect to Sample B. Large grains at the surfaces originated from high temperature homogenization are known to affect the mechanical properties of aluminum foils used in finstock applications negatively and lead to failures in formability [8].

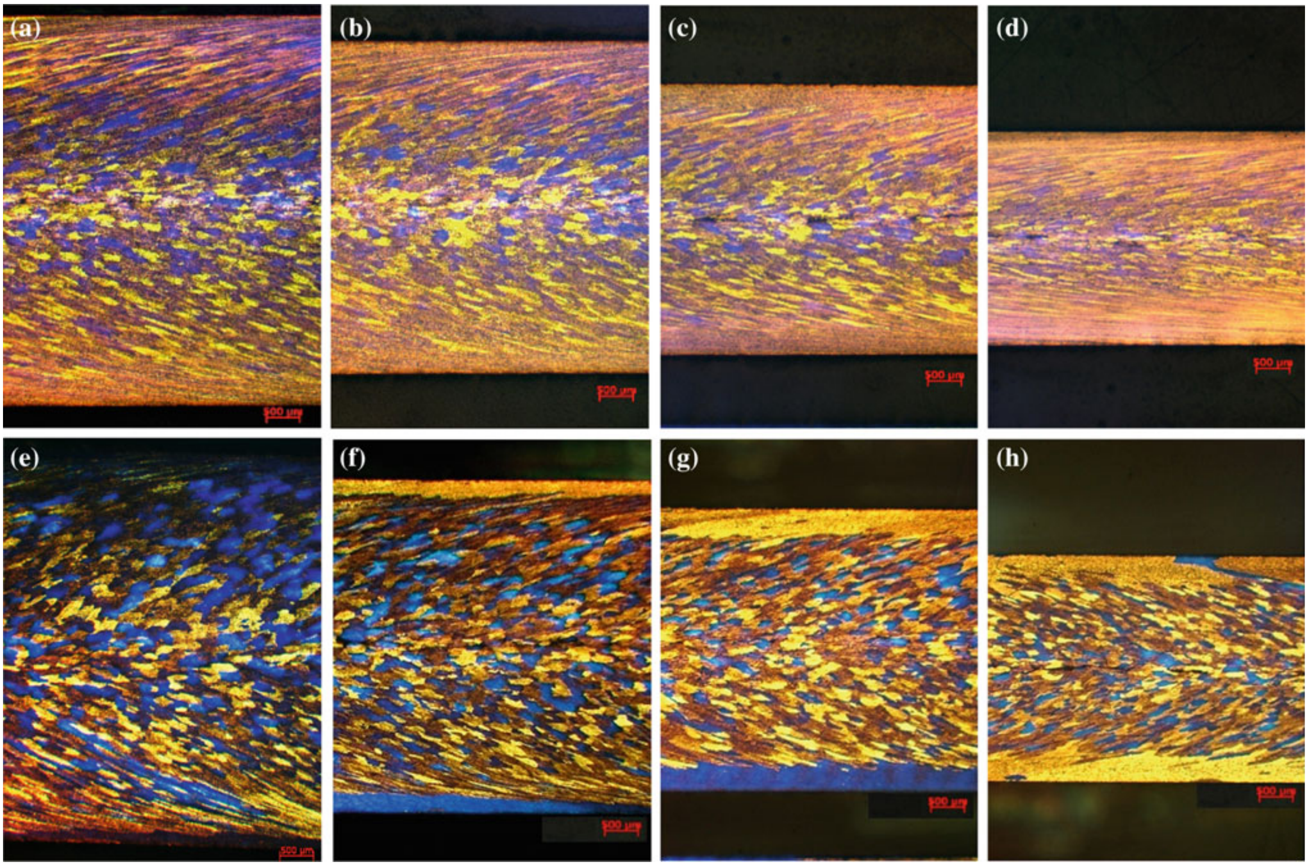

**Fig. 4** Grain structures of **a–d** as-cast samples, 6, 5, 4, 3 mm respectively, **e–h** homogenized samples—6, 5, 4, 3 mm respectively

## Conclusions

The strip thickness is an important factor affecting the microstructure, segregation behavior and the strength of the material at the as-cast state. These are the most important features of an as-cast material, which influences not only the final properties but also the rolling behavior of a product. Depending on the critical characteristics of a product, the strip thickness can be used as a tool to find an optimum between the quality and the productivity of the overall process.

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