Segregation Mechanisms and Their Effects on the Aluminium Flat Rolled Products (Sheet/Foil) Produced by Twin Roll Casting Technology

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Abstract

Twin Roll Casting (TRC) technology has significantly higher solidification rates compared to conventional casting methods. The surface microstructure of the as-cast sheet produced with TRC typically shows a matrix supersaturated by alloying elements, while it also contains segregation along the centerline of the as-cast sheet. Surface and edge segregations also can be visible in as-cast materials. Segregation affects the final material properties in terms of the mechanical properties, corrosion properties, number of pinholes, and rolling performance. It is extremely important to eliminate or reduce the intensity of the segregation. In this study, the formation mechanisms and parameters for minimizing centerline segregation in 8xxx aluminum foil alloy cast with steel–steel and copper–copper shell pairs are investigated. Both surface and edge segregations are also studied. As-cast samples are prepared metallographically and investigated by using light microscope, scanning electron microscope equipped with EDS. Electrical conductivity measurements are also performed.

Keywords

Twin roll casting • Segregation • 8xxx wrought aluminum alloy

Introduction

Twin roll casting (TRC) has been popular for producing thin aluminum strips. The TRC process produces strips directly from liquid aluminum by feeding molten metal into the gap of two rotating water-cooled rolls. As a result, it solidifies and forms a solid shell on each roll surfaces with considerable amount of hot rolling before reaching the roll nip [1, 2]. TRC technique can provide lower operating costs, less energy consumption, and lower scrap rate compared to traditional DC casting method. During casting of aluminum alloy, process parameters such as liquid metal temperature, strip speed, water cooling, separating force, and amount of graphite affect the microstructural properties of the sheet such as grain morphology, distribution of alloying elements, the size and distribution of intermetallic particles, and the macro/micro-segregation [3]. Also, the alloy composition and the caster shell material (i.e. copper, steel) have a great influence on the surface properties of the cast material and its microstructure.

Due to the non-equilibrium solidification conditions, a supersaturated region of alloying elements near the surface appears and the centreline segregation reveals at the mid-plane of the as-cast sheet thickness. Such formations have different effects on the final sheet or foil material properties in terms of the corrosion properties, mechanical properties, surface defects, pinhole, and rolling performance. Therefore, it is important to eliminate or reduce the intensity of the macro- and micro-segregations for the downstream process efficiencies [4]. Steel caster rolls, which are widely used in the twin roll casting method, affect productivity and shell life, although they have different alloy grades, mechanical properties and thermal properties. Recently, due to having high thermal conductivity properties, copperalloy-based casting shell materials are used in twin roll casting. By using copper shells having high heat transfer capability from the liquid metal, different microstructural features are obtained [9]. In addition, high-temperature heat

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treatment of the cast material at different temperatures reduces the intensity of the centerline segregation, which usually remains until the final product. Another issue that is most problematic in the TRC process is edge cracking, which causes difficulties in downstream processing of strips. Edge cracking is caused by the rolling and solidification effect when the liquid metal comes in contact with the caster shell. During the twin roll casting process, edge cracks with different types can be seen depending on the alloy and casting parameters. Parameters such as liquid metal flow rate, liquid metal level, temperature, and graphite concentration applied to the shell surface must be kept under control to prevent edge cracking [1, 5–8].

In this study, the segregations encountered in the production of 8xxx series aluminum foil alloy produced by the twin roll casting method are investigated. Microstructural components and electrical conductivity measurements of cast sheets produced with copper and steel shells are compared. Edge cracks and surface segregations are investigated by scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS).

Experimental

In this study, 8xxx (Twin roll cast AlFeMnSi alloy) aluminum foil alloy is used and its chemical composition is given in Table 1. Pechiney Jumbo 3CM-type twin roll caster consisting of steel/steel pair and copper/copper pair rolls are used to produce strips with the thickness of 7,5 mm. Samples taken from the as-cast sheets produced by steel–steel and copper–copper pair shells are investigated for the microstructural characterization. In order to understand the effect of low- and high-temperature heat treatment on the centerline segregation, samples are heat treated at 480 °C for 8 h and 580 °C for 8 h, respectively. The surface quality of strips, namely, edge cracks and surface segregation defects are checked and samples are taken for the investigation. All samples of microstructure are metallographically prepared and investigated using light microscope (LM, Zeiss Scope A1-Vario) and SEM (Zeiss Evo MA15).

Table 1 Chemical composition of the samples

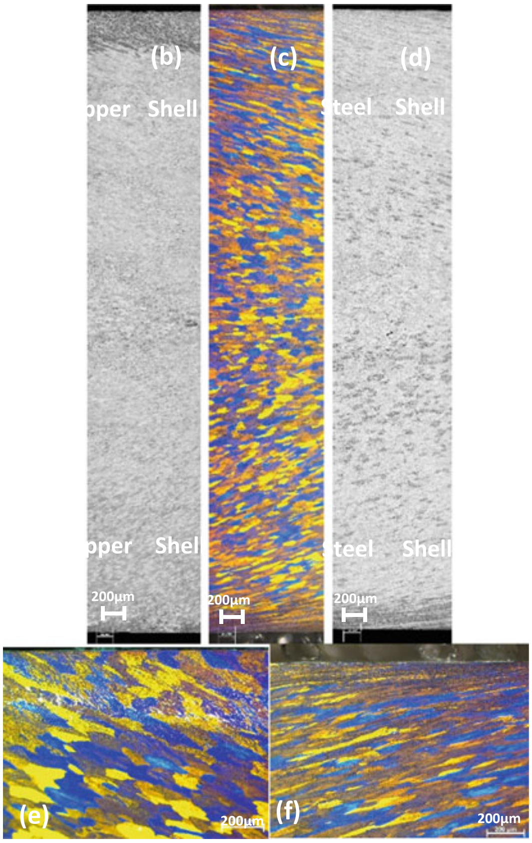
Weight-%				
Si	Fe	Cu	Mn	Ti
0,1–0,3	1,2–2,0	0,01–0,1	0,4–1,0	0,01–0,03

Results and Discussion

Figure 1 shows the microstructures of the as-cast sheets produced by steel–steel and copper–copper pair caster rolls. At the near-surface location of the solidification structure, both microstructures show both relatively higher density of secondary phases and smaller grains compared to the center of the cast material cross section. Although the center of solidified structure exhibits a equiaxed grain structure, grains on the surface appear in an elongated morphology in the direction of casting. Compared to the use of steel shell (Fig. 1f), relatively larger equiaxed grains and finer intermetallics are observed on the surface after the use of copper shell (Fig. 1e). This phenomenon is attributed to the rapid cooling effect due to the high thermal conductivity of copper.

As shown in Fig. 1, less centerline segregation encountered in production with copper shell is observed, although it is strongly affected by casting parameters (strip speed, tundish temperature, separating force, tip position, and cooling temperatures).This is related to the over-saturation of the matrix with alloying elements due to the rapid cooling effect. As-cast strip thickness of the material is 7,5 mm. With the data obtained from the electrical conductivity measurements, an inference can be made on the solidification characteristic. Electrical conductivity values of the material decrease with increasing solute elements dissolved in the matrix. While the conductivity values on the sheet produced with the copper shell are 21.3 MS/m (480 kHz) and 32,2 MS/m (240 kHz), this conductivity values on the sheet surface produced with the steel shell are determined as 21.0 MS/m (480 kHz) and 36,4 MS/m (240 kHz). For aluminum materials and a probe frequency of 480 kHz the penetration depth is 120 µm. A change in the probe frequency to 240 kHz leads to a penetration depth of 180 µm. Low electrical conductivity values obtained from the as-cast sheet surface produced with copper shell indicate that the matrix is more saturated with the alloying elements. It should always be taken into account that higher casting rates increase productivity, but can cause a macro-segregation in the middle of the casting material despite the use of a steel or copper shell.

The eutectic centerline segregation caused by the high casting speed in sheet material produced with steel shell is given in Fig. 2a, b. It is a fact that formed segregation within the solidified structure affects the final material properties in terms of the mechanical properties, corrosion properties, number of pinholes, and rolling performance. As it is well



(e) (f)

Fig. 1 LM micrographs showing the grain structures of a twin roll cast 8xxx series alloy produced with (**a**, **b**, **e**) copper shell and (**c**, **d**, **f**) steel shell

known, homogenization heat treatment is needed to eliminate in homogeneities, micro-segregations, residual stresses, and other defects that occur in the material during non-equilibrium solidification conditions that occur during the production process. Such a process is also desirable in industrial products that require increased deep drawability. However, although the density of mentioned discontinuities decreases with heat treatments, they do not disappear completely. After casting, the samples are subjected to homogenization heat treatment both at 480 and 580 °C for 8 h to observe the evolution of centerline segregation. SEM images showing the heat-treated matrices are given in Fig. 2c–f. EDS analysis indicates that the eutectic and intermetallic particles (Fig. 2b) are Fe–Mn–Si–Al based. As it can be seen in Fig. 2c–f, morphologies of the centerline segregation phases transformed into the spherical- or needle-like intermetallics. In addition, EDS analysis shows that the amount of Fe, Mn, and Si elements dissolved in the matrix decreases after heat treatment due to the formation of coarser intermetallic particles.

Casting parameters are extremely important in copper shell castings, as higher speeds are achieved compared to standard steel shell castings. As seen in Fig. 3a, as-cast sheet surface may have surface segregations due to the higher strip speed and different solidification conditions. In Fig. 3a, two different regions (marked with number 1 and 2) can be seen on the as-cast sheet surface. According to the SEM, SE, and BSE images, these two regions have different topographical features and different intermetallic phase morphologies. Eutectic intermetallic formation can be seen due to the high

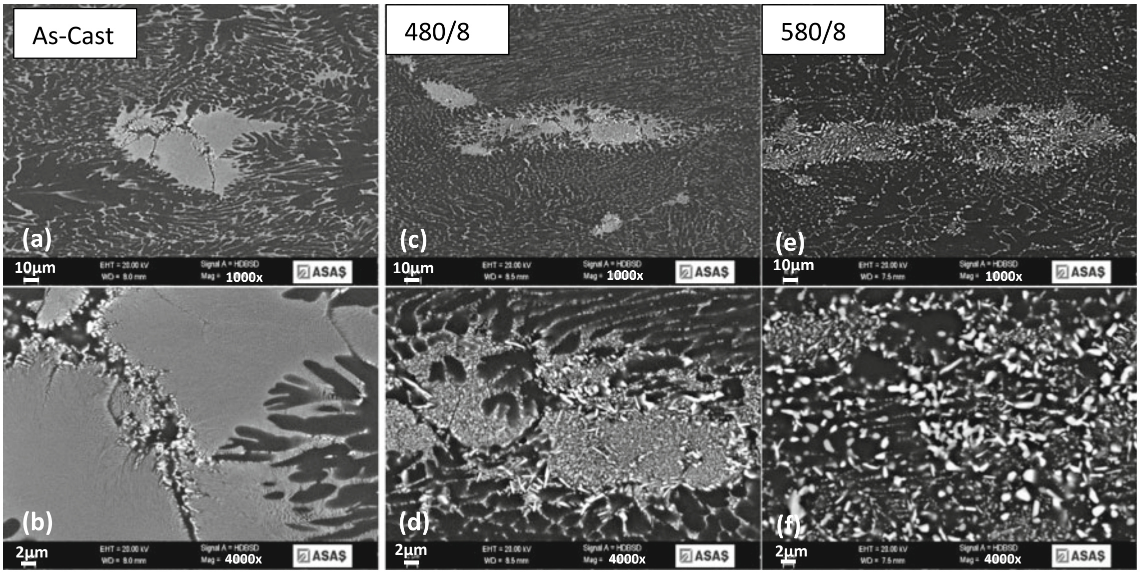


Fig. 2 SEM micrographs showing the structure of cast alloy (**a**, **b**), heat-treated alloy at 480 °C for 8 h (**c**, **d**) and 580 °C for 8 h (**e**, **f**)

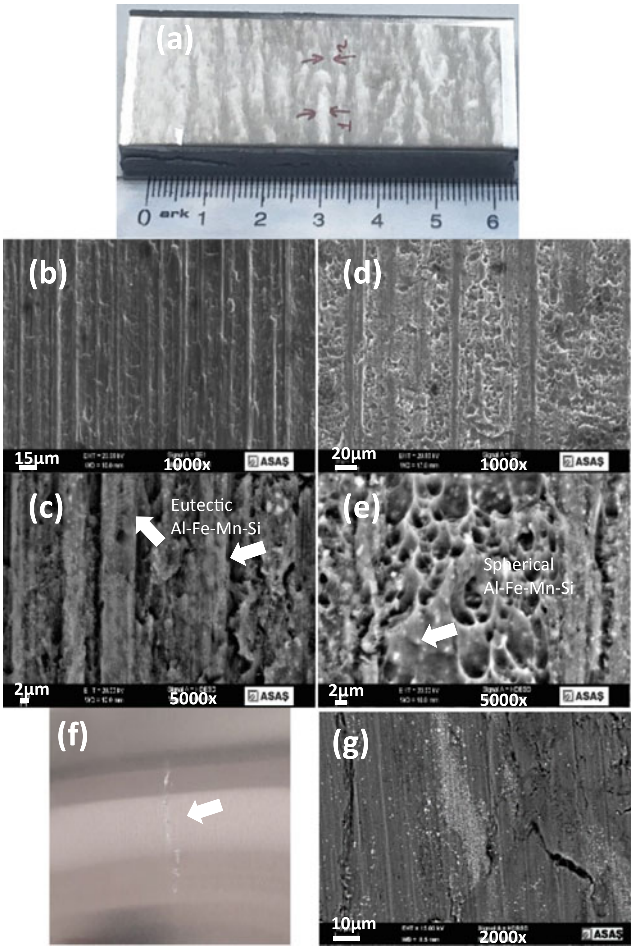


Fig. 3 **a** Macro-image of as-cast sheet material surface produced with copper shell; **b**, **c** SEM images of segregated area marked with number 1; **d**, **e** segregated area marked with number 2; **f** macro-image of surface defect on aluminum foil material; **g** BSE image of surface defect

solidification rate (Fig. 3c) and the particulated intermetallic phase formation appears due to the low solidification rate conditions (Fig. 3e). These kinds of segregations can cause surface defects (Fig. 3f, g) during cold rolling process to lower thicknesses. The inhomogeneity and different localized amounts of the graphite coating on the casting roll surface with the combined effect of the insufficient cooling conditions related to the casting parameters can cause surface segregations.

In twin roll strip casting process, the quality of the strips is an important issue. Regarding the surface quality of the strips another surface quality defect is edge cracking. The different microstructure at the edge is formed due to the casting speed, rolling effect, alloy composition, liquid metal flow, solidification behaviour, etc. Typical macro-image of the crack formation on the edges is given in Fig. 4a It can be seen clearly a macro-crack formed in the edge of strip and extending along the TRC direction. Metallographic samples prepared from the edge of the crack area were investigated from the regions marked with 1 and 2 in Fig. 4a. Optical micrographs of the samples close to the crack tip marked with redline 1 and away from the crack tip marked with redline 2 are shown in Fig. 4c, d, respectively. It is clearly seen that a high volume of intermetallic phases (segregation) have formed in the vicinity of the crack area. Therefore, it can be concluded that the edge crack was initiated from the segregation line. During the casting process milling equipment enables accurate in-line milling of strip edges to eliminate solidification heterogeneities on the edges. However, crack roots may remain when edge milling operation is insufficient. In these cases, rolling defects may be encountered in downstream processes as seen in Fig. 4e. According to the BSE images of the problematic areas, the crack formation occurred due to the segregations related with the as-cast strip edge cracks.

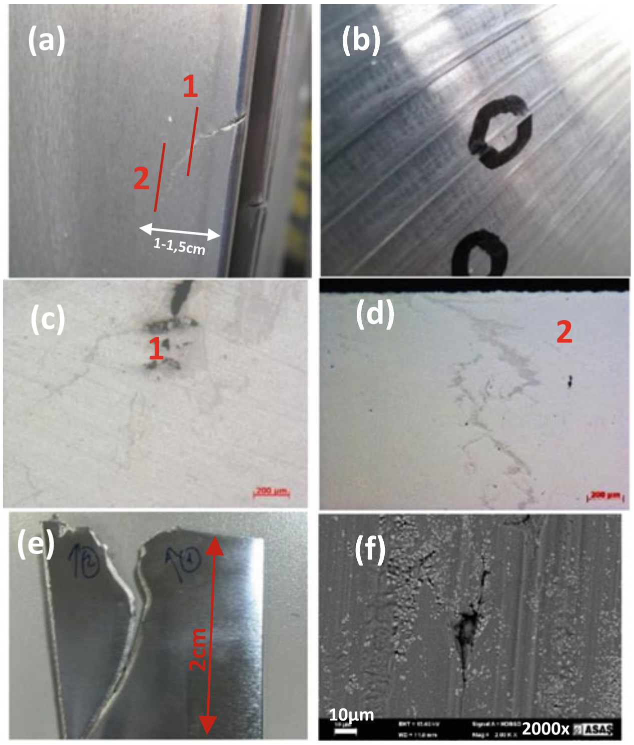


Fig. 4 Macro-images of; **a** as-cast sheet material edge, without any edge trimming. **b** Edge trimmed as-cast coil side surface. Optical microscope images of samples; **c** close to the crack tip marked with redline 1; **d** away from the crack tip marked with redline 2; **e** macro-image of crack formation on the edge of strip; **f** BSE images of crack area

Conclusions

Due to the high thermal conductivity of copper, relatively larger equiaxed grains and finer intermetallics are observed on copper shell which produced surface strip than that of steel shell produced surface strip. Although it is strongly affected by casting parameters (casting speed, separating force, temperatures, etc.), less centerline segregation was observed in strip produced with copper shell rollers.

Depending on the different solidification conditions related to the casting parameters and the high productivities achieved by using copper shell, segregation formations may occur on the as-cast sheet surfaces. If no precautions are taken, segregations can lead to quality defects in the downstream processes.

Most effective process parameters for the solution of segregation regardless of the alloy content are

- Decreasing the cooling water temperature to ensure uniform cooling condition on as-cast sheet surface.
- Reduce the casting speed.
- Reduce the casting temperature appropriately.
- Spraying homogenous graphite on to the caster shell surface.
- Promote fine equiaxed grain structure in both casting process and subsequent homogenization annealing

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