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Melt Conditioned Twin Roll Casting Process for Aluminium Alloys

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Aluminium alloy strip has been successfully cast using the Melt Conditioned Twin Roll Casting (MC-TRC) process. The liquid metal to be strip cast was fed into a melt conditioner where it was intensively sheared under conditions of high shear rate and high turbulence induced by co-rotating twin screws. Melt conditioning provides a melt which has uniform temperature and chemical composition and well dispersed nuclei. The conditioned melt was then directly fed into a twin roll caster. The MC-TRC technology produced high quality Al-Mg alloy strip with fine and equiaxed grains uniformly distributed throughout the cross section. The chemical composition of MC-TRC strip was uniform across the cross section and there was minimal centre line segregation compared to conventional TRC strip. Grain refining efficiency was enhanced by melt conditioning.

Keywords: *Melt Conditioned Twin Roll Casting; Twin Roll Casting; Al-Mg alloys; Segregation;*

1. Introduction

AA5xxx alloys like AA5754 and AA5182 are used as structural components in automotive. Generally flat, wide alloy sheets is produced from direct chill (DC) cast rolling blocks that are hot and cold rolled to final gauge before final annealing. Twin roll caster can directly cast strip at the hot roll transfer gauge [1] and can potentially reduce processing costs provided that surface defects are controlled as no scalping is possible and that comparable levels of properties and formability are achieved at the annealed final gauge as supplied for automotive manufacture. Various direct strip casting processes have been developed over the last fifty years and they are broadly classified as belt caster, single roll caster and twin roll caster, but each has its own limitations [2]. Twin roll casting (TRC) is a near net shape casting process which can produce sheets of 3-7 mm in thickness directly from liquid metal. TRC effectively combines casting and hot rolling. However issues with surface quality and severe segregation at the centre-line and surface have limited commercial exploitation to alloys suitable for packaging and architectural applications [3-6].

The melt conditioned twin roll casting (MC-TRC) process has been developed at the Brunel Centre for Advanced Solidification Technology (BCAST) to overcome the limitations faced by the conventional TRC process [7]. The combined action of high shear rate and high degree of turbulence from MCAST process makes the feed liquid into a conditioned melt which has uniform temperature and chemical composition and well distributed nuclei. After processing, the conditioned melt is fed into the twin roll caster. In the present study, we report results on the production of 5754 Al based alloy strip made from the MC-TRC and conventional TRC processes.

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2. Experimental details

The chemical composition of the base AA5754 alloy used in this work was Al 3wt%Mg, 0.25wt%Fe, 0.08wt%Si, 0.45wt%Mn, 0.08wt%Cu. Additions of Fe, Si and Cu were made to represent the introduction of impurities from post consumer scrap in the alloy formulation. The alloys were melted in a clay graphite crucible at 755˚C and melts were added with grain refiner (GR) using 0.1 wt.% of an Al-5Ti-1B master alloy at 755˚C, 10 minutes before casting to avoid settling. A laboratory scale horizontal twin roll caster was used to produce the alloy strip. The liquid metal was fed into the roll gap from a preheated tundish. The water cooled steel rolls were 318 mm in diameter and 350 mm in width. Before each experiment the rolls were cleaned and coated with graphite to avoid the sticking of cast metal. The roll gap was set at 3 mm and the tundish tip was set back 43 mm from the centre of the roll gap. Casting was carried out at 2 m/min. The schematic view of the MC-TRC unit is shown in the Fig.1. Melt conditioning was carried out at 500 rpm at 655˚C for 60 sec and the conditioned melt was transferred and poured into the preheated tundish for strip casting. A more detailed description of the melt conditioning mechanism can be found elsewhere [7-10]. TRC strip was also cast without conditioning the melt. Microstructural analysis was carried on both the transverse and longitudinal cross-sections of the TRC and MC-TRC strip. Mounted specimens were mechanically polished and electrolytically etched with Barker's reagent at 20V for 1 min to reveal the grain structure. Zeiss Axio Vision optical microscopy was used for the microstructural analysis and the line intercept method was used to measure the grain size along the transverse section. A Zeiss EVO 50 scanning electron microscope (SEM) equipped with energy dispersive spectroscopy (EDS) was used to analyse the intermetallic phases and qualitative chemical composition.

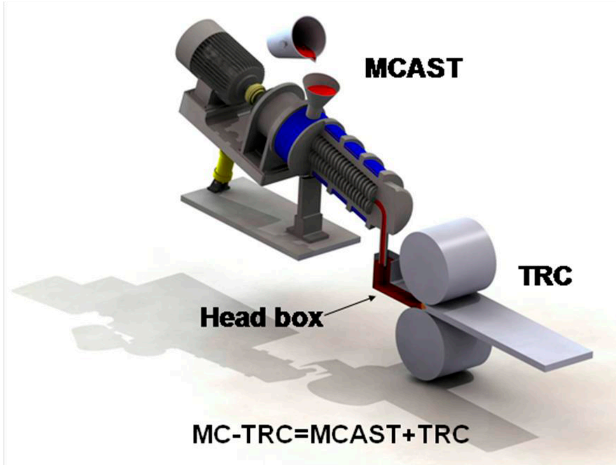

Fig. 1 Schematic view of Melt Conditioned Twin Roll Casting (MC-TRC)

3. Results

3.1 Grain size

Figure 2(a) shows the microstructure of the as-cast TRC strip that has a grain size of 120 ± 8µm compared to the MC-TRC processed strip (Fig. 2(b)) with a grain size of 111 ± 5 µm. With the addition of 0.1 wt.% GR, the TRC strip shows (Fig. 3(a)) fine grain and the grain size decreases to 85 ± 7 µm. Similarly, the grain size (Fig. 3(b)) was further reduced to 74 ± 4 µm with the addition of GR for the MC-TRC strip. The strip produced from the scrap analogue alloy with MC-TRC process shows uniform and fine grains of 121 ± 4 µm in size whereas (Fig. 4(b)) the TRC processed strip had larger grains of 190 ± 13µm in size (Fig. 4(a)).

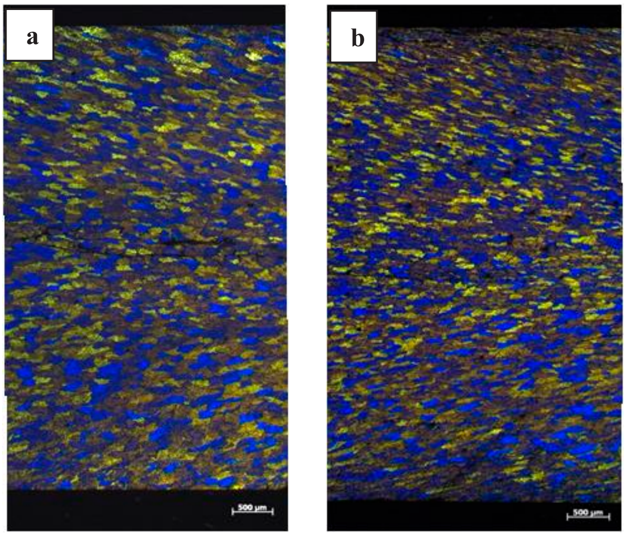

Fig. 2 Microstructure of (a) TRC and (b) MC-TRC strip along longitudinal cross-section

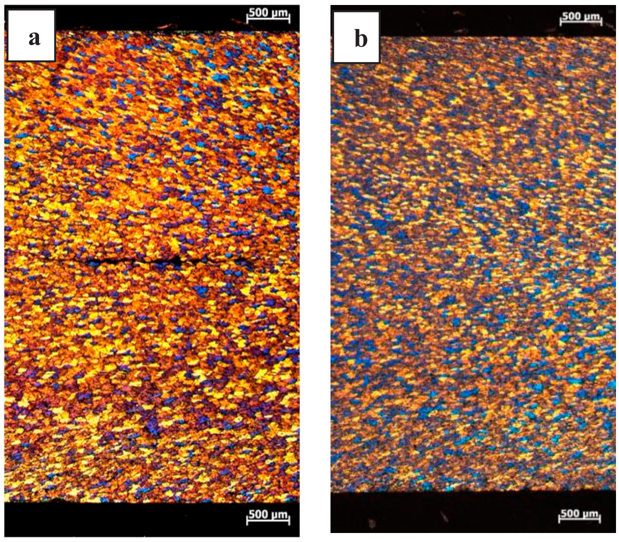

Fig. 3 Microstructure of (a) TRC and (b) MC-TRC strip with grain refiner along longitudinal cross-section

3.2 Segregation

Severe segregation of the alloying element was evident at the centre of the TRC processed strip (Fig. 2(a)). Centre line segregation was not observed for the MC-TRC processed strip (Fig. 2(b)). The addition of GR not only reduces the grain size but also minimizes the severity of the segregation (Fig. 3(a)). Similar segregation free microstructure is observed on the MC-TRC processed strip of scrap analogue alloy (Fig. 4(a)). The EDS elemental analysis (Fig. 5(a)) on the cross section of the TRC strip clearly shows the evidence for segregation of alloying elements such as Fe, Mg and Mn at the centre. In contrast, MC-TRC strip shows (Fig. 5(b)) uniform distribution of the alloying elements throughout the cross section. SEM analysis on near surface of TRC strip reveals (Fig. 6(a)) fine intermetallic phases such as AlFeMn, and Mg_2Si distributed along the cell boundary, whereas at the centre of the strip (segregated regime) higher volume fraction of intermetallic phases such as AlFeMnSi and Mg_2Si are observed (Fig. 6(b)). Such severe centre line segregation was not observed in MC-TRC strip.

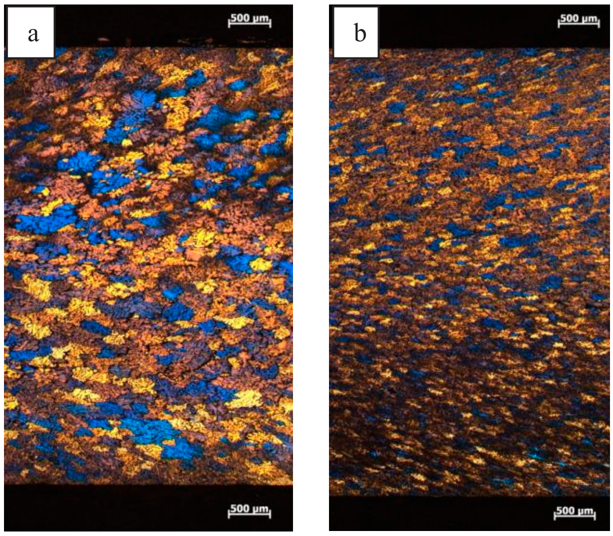

Fig. 4 Microstructure of (a) TRC and (b) MC-TRC strip from a scrap analogue alloy along longitudinal cross-section

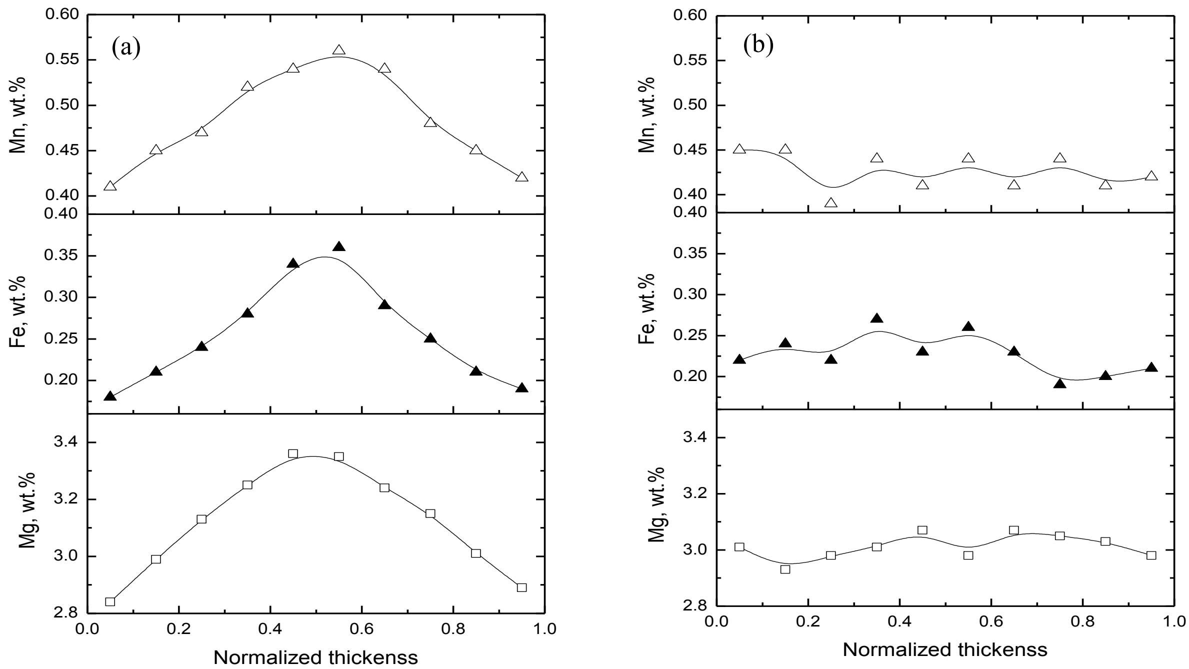

Fig. 5 EDS elemental analysis on longitudinal section of (a) TRC and (b) MC-TRC primary alloy strip

4. Discussion

4.1 TRC process

Microstructural analysis on TRC strip shows coarse grains with severe centre line segregation. In TRC process, solidification starts from the water cooled steel roll surface. Thus the growing dendrites from rolls surface interact at centre resulting in solute rich segregation and non-uniform grains [11]. Observed centre line segregation in TRC strip is also attributed to the compressive action of roller on the semi-solid sump. Under load the solute rich cold liquid squeezes out from the semi-solid sump (central region) to the hot liquid region and pumps back the hot liquid to the semi-solid sump where it melts the primary solid. Thus subsequent solidification results in the formation of solute rich channel called centre line segregation or channel segregation. This explains the reason for presence of solute rich intermetallic phase at the centre of the TRC strip (Fig. 6(b)). Lockyer *et al* [12] reported similar type of micro and macro defects that commonly observed in various Al alloy strip cast by conventional TRC process. It is important to point out that the Brunel TRC caster is operated with free load condition which also helps in reducing the severity of the microstructural defect such as centre line segregations.

Though the addition of grain refiner reduces the grain size of TRC strip the microstructure still shows centre line segregation. This segregation level is smaller when compared to the segregation found in the strip cast without GR. It can be understood that the uniform chemical composition along the cross-section of the strip is mainly attributed to the fine grains. During solidification the excessive solute elements (above α-Al solid solubility) are rejected along the grain boundary. Thus the large grain boundary area in the grain refined alloy can accommodate more solute elements and as result less solute segregates (centre line segregation) at the centre of the strip. Copper and Fishers [13] has studied the effect of range of different grain refiner on the grain refining efficiency of the strip cast Al alloy. They observed that the amount and type of GR that need for refining the grain size of TRC strip is different than that used for other conventional casting process.

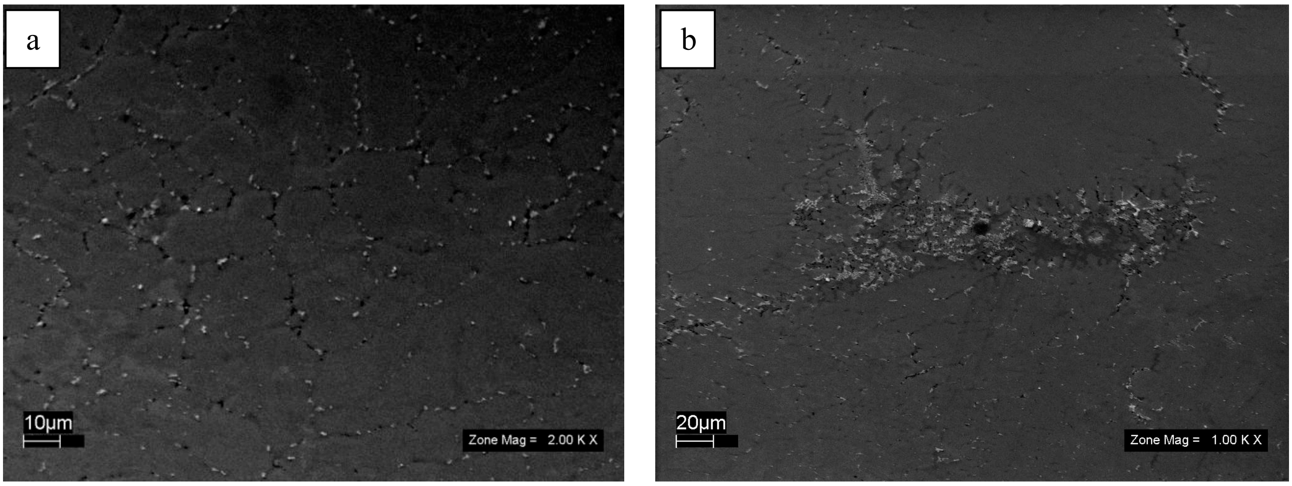

Fig. 6 SEM micrographs of (a) near surface and (b) centre of primary Al alloy TRC strip

4.2 MC-TRC process

It is interesting to observe that without addition of grain refiner, MC-TRC processed strip shows fine grains and uniform chemical composition throughout the cross-section. Unlike TRC, MC-TRC does not show the presence of centre line segregation. This could be due to the conditioning of liquid metal before casting. Melt condition provides uniform temperature and uniform chemical composition with well dispersed nuclei throughout the volume of liquid [14]. Under intensive forced convection the survival rate of nuclei are enhanced further and results in fine equiaxed grains. Intensive melt shearing breaks the harmful oxide bi-films and oxide particle clusters and disperse them uniformly through out liquid. Such forced wetted dispersed oxide particle at critical under cooling act as nucleating substrate for α-Al and intermetallic phases [9]. Thus the strip produced from MC-TRC process result in fine uniform grains, uniform chemical composition and absence of centre line segregation.

The combination of addition of grain refiner and melt conditioning the melt, the strip shows fine grains uniformly distributed without any segregation. Al-5Ti-1B master alloy which was added as grain refiner consist of Al_3Ti and TiB_2 particles. These particles act as potent nucleating sites for α-Al during solidification. In most cases, these particles exist as clusters (dead nuclei) in the master alloy. During melt conditioning these clusters of potent substrates are finely broken and distributed uniformly in the melt and result in increased grain refining efficiency. Venkateswarlu et al, [15] and Zhang et al [16] have also observed similar increase in efficiency of the grain refiner after thermo-mechanical processing. Thus the combined grain refinement with melt condition result in fine equiaxed grains without any centre line segregations on the TRC processed strip.

4.3 Direct recycling of clean Al scrap

MC-TRC process for the first time successfully demonstrated to produce high quality strip from pure Al scrap. The microstructure of MC-TRC processed Al scrap strip shows fine and uniform grains throughout cross-section without centre line segregation. In general, Al scrap consists of different level of impurities and inclusions. These impurity elements, such as Fe, Mn, Si, Cu, etc react with other standard alloying elements and result in the formation of brittle intermetallic phases. These intermetallic phases could act as a barrier for subsequent thermo-mechanical and forming process [17]. Similarly the presences of inclusions (such as oxide particles and bi-films) further degrade the downstream thermo-mechanical process. As the level of impurities and inclusions increases the amount of segregation at the centre of the TRC strip also increases. Whereas in MC-TRC process as explained above, the microstructure refinement distributes the solute rich intermetallic phases along the grain boundary and results with minimal segregation. In addition, Fang et al [18] studied the effect of intensive melt shearing on the modification of Fe based intermetallic phases. They demonstrated that the intensive shearing reduces the diffusion and thermal field in front of solid/liquid interface which result in reduced tendency of preferential growth during semisolid processing. In MC-TRC process, the inclusion clusters are de-agglomerated and distributed uniformly to have positive effect on the downstream process. Therefore the combined fluid dynamic and high shear dispersive action experienced by liquid during melt conditioning result in more homogeneous microstructure in MC-TRC produced Al scrap strip.

5. Conclusion

Al-Mg alloy strip was successfully cast from MC-TRC and TRC processes. MC-TRC strip shows fine grain structure and uniform composition with minimal segregation when compared to TRC process. The combined addition of grain refiner and MC-TRC processed strip show very fine and equiaxed grain distributed throughout the cross-section without any segregation. For the first time MC-TRC process was successfully used to produce high quality strip from Al scrap analogue alloys. Therefore it can be concluded that MCAST process is the effective way to control the nucleation and equiaxed grain growth.

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