Proceedings of the 9th International Conference on Aluminium Alloys (2004)
Edited by J.F. Nie, A.J. Morton and B.C. Muddle
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Possibilities of Rapidly Solidified Thin Strips Produced by a Twin Roll Caster for New Alloy Development and High-grade Recycling of Widely-used Conventional Alloys

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Keywords: Recycling, Aluminum alloy, Twin-roll caster, Rapid solidification, Mechanical properties

Abstract

The rapidly solidified A356 and 6063 alloy strips were fabricated by using a twin-roll caster equipped with water-cooled copper-rolls. The A356 alloy strip with fine primary Al dendrites and eutectic Si particles was heat-treated and cold-rolled to form a thin sheet. The sheet showed significantly improved formability compared to the sheet fabricated from the conventional cast product. The rapidly solidified cast strip of the 6063 alloy with high Fe content was also cold-rolled and heat-treated to a thin sheet. Increase in Fe content resulted in refined grain size. No detrimental effect of Fe was evident except for reduced precipitation hardening.

1. Introduction

Even when various kinds of downstream processing and heat treatment are performed, solidification structure of the starting product is important since the initial solidification structure can strongly influence the mechanical, physical and chemical properties of the final product. Generally, rapid solidification can provide (i) grain refinement, (ii) supersaturation of relatively insoluble elements and (iii) fine and homogeneous distribution of secondary particles. In view of these benefits, fabrication of alloy strips at a high cooling rate is considered to be one of the answers to alleviating the detrimental effect of impurities [1].

Strip casting is a method for producing a plate directly from an alloy melt. Rapid solidification can be achieved by using twin-roll casters. At present, however, the vast majority of commercial twin-roll casters produce sheet aluminum plate of around 6mm thickness. Producing strips at thinner gages is of interest, because this would allow increase in cooling rates and improvement in material properties. The present study aims to demonstrate the importance of fine solidification structure of thin strip fabricated by the twin-roll caster not only for improvement in deformability of the cast alloy but also for high-grade recycling of widely-used conventional wrought alloys.

2. High Speed Twin-Roll Caster

In twin-roll casting, molten metal is fed onto water-cooled rolls. Solidification begins when the molten metal comes into contact with the casting rolls, and the progressively reducing dimension of the roll bite forces the solidifying metal to remain contact with the rolls. Figure 1 shows two types of twin-roll casters used in the present study [2,3] ; (1) a melt drag twin-roll caster (MDTRC), and (2) a hydrostatic press twin-roll caster (HPTRC). Both roll casters are equipped with a pair of water-cooled pure copper rolls, and no lubricant is employed on the roll surface. The rolls have a diameter of 300mm and a face width of 100mm.

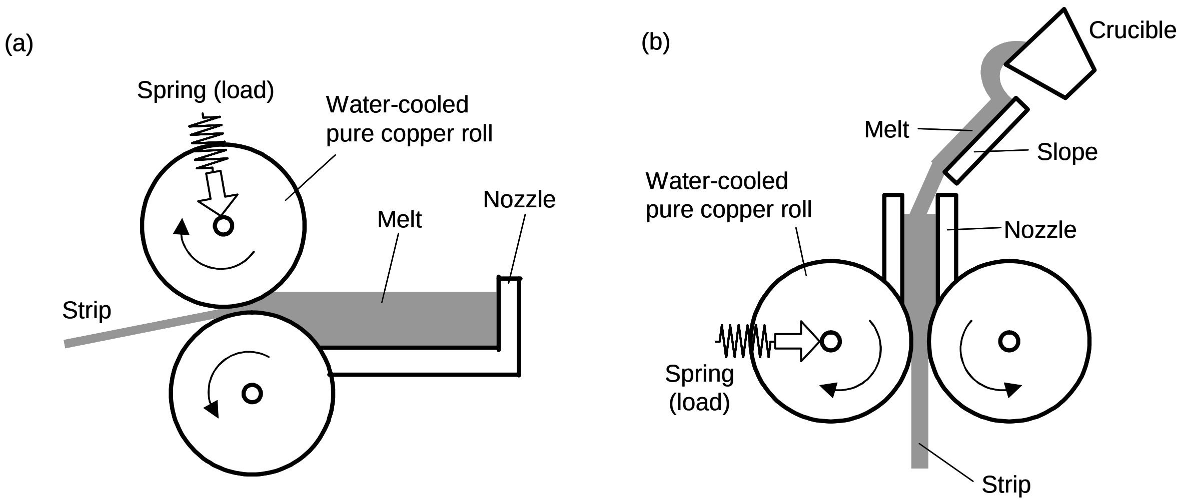


Figure 1: Two types of twin-roll casters used in the present study. (a) melt drag twin-roll caster, (b) hydrostatic press twin-roll caster.

3. Microstructure and Mechanical Properties of the Twin-roll cast A356 alloy

The material selected in the present study is A356 aluminum alloy. The alloy was melted at 898K. The cast strip was fabricated at a speed of 20m/min for the MDTRC, and 90m/min for the HPTRC. The width and thickness of the resultant strips were 35mm and 2.5mm for the MDTRC, and 100mm and 2mm for the HPTRC. The melt was also cast into a conventional book-type permanent mold (20mm thickness).

Optical microstructural observation was made for the transverse cross section of the cast plate fabricated by MDTRC. A fine dendrite structure (DAS: 3.5μm) was obtained near the bottom surface. In the mid-thickness region, equiaxed grains and a condensed eutectic solidification region were observed (DAS: 6.5μm). Two types of solidified structure (coarse floating dendrite crystals and a fine dendrite structure) were observed at the near top surface region (DAS:14.2μm and 3.6μm). In the case of HPTRC, fairly refined primary dendrite and eutectic solidified structure was observed. DAS was 2.6μm for the near-surface region and 4.5μm for the mid-thickness region. In contrast, the permanent mold cast plate had a DAS of 32.2μm.

The relationship between DAS and cooling rate for A356 alloys was investigated previously, as shown in Figure2 [4]. The relationship can be used to estimate cooling rates of the cast strip from the obtained DAS values. The estimated cooling rate at the near-surface region of the HPTRC product is 4000K/s, and that for the mid-thickness region is 500K/s.

For the MDTRC strip, the estimated maximum cooling rates is 2000K/s at both the near bottom and the near top surface region.

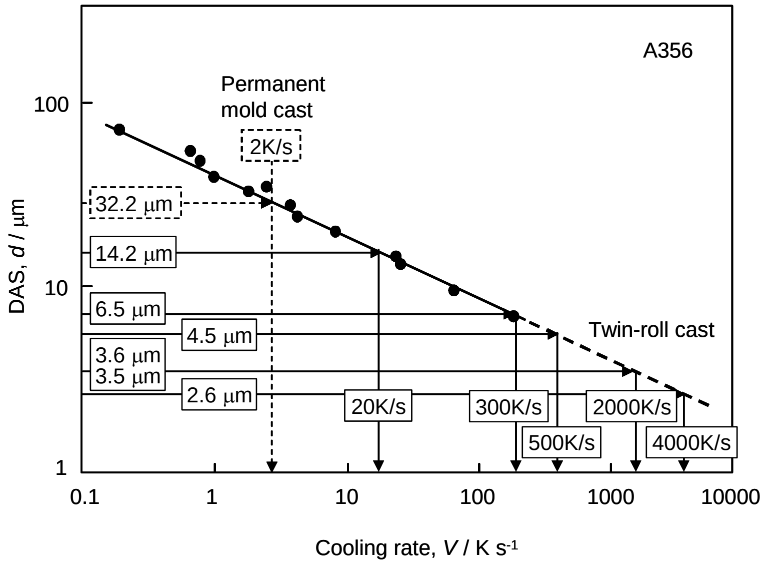


Figure 2: Relationship between DAS and cooling rates for A356 alloy.

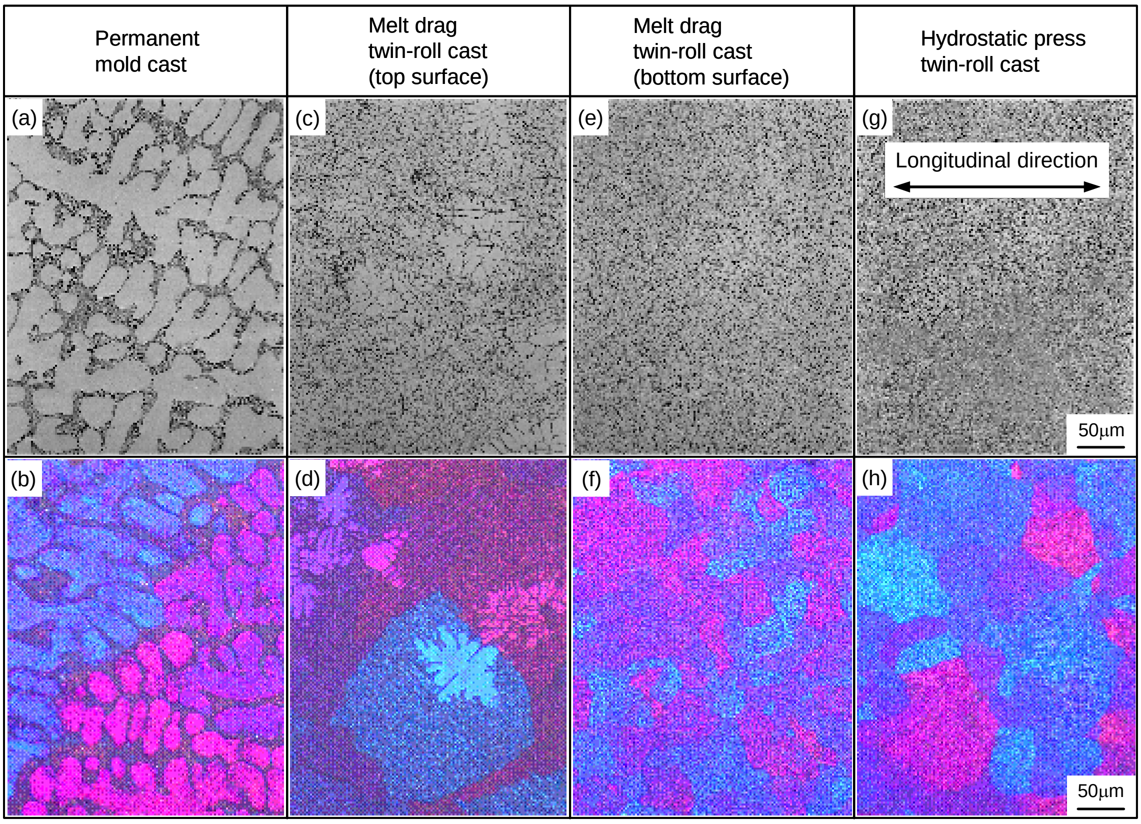


Figure 3: Surface structure of the cast plate (as-polished structure in the upper column and anodized structure in the lower column). (a), (b) permanent mold cast, (c)~(f) MDTRC, and (g), (h) HPTRC.

The surface structure of the cast plate is shown in Figure 3. A large difference is observed between the top surface and the bottom surface of the MDTRC plate. These cast plates were homogenized at 803K for 14.4ks, cold-rolled into a 0.5mm thick sheet and then annealed at 723K for 14.4ks. Figure 4 shows optical micrographs of the sheet surface for

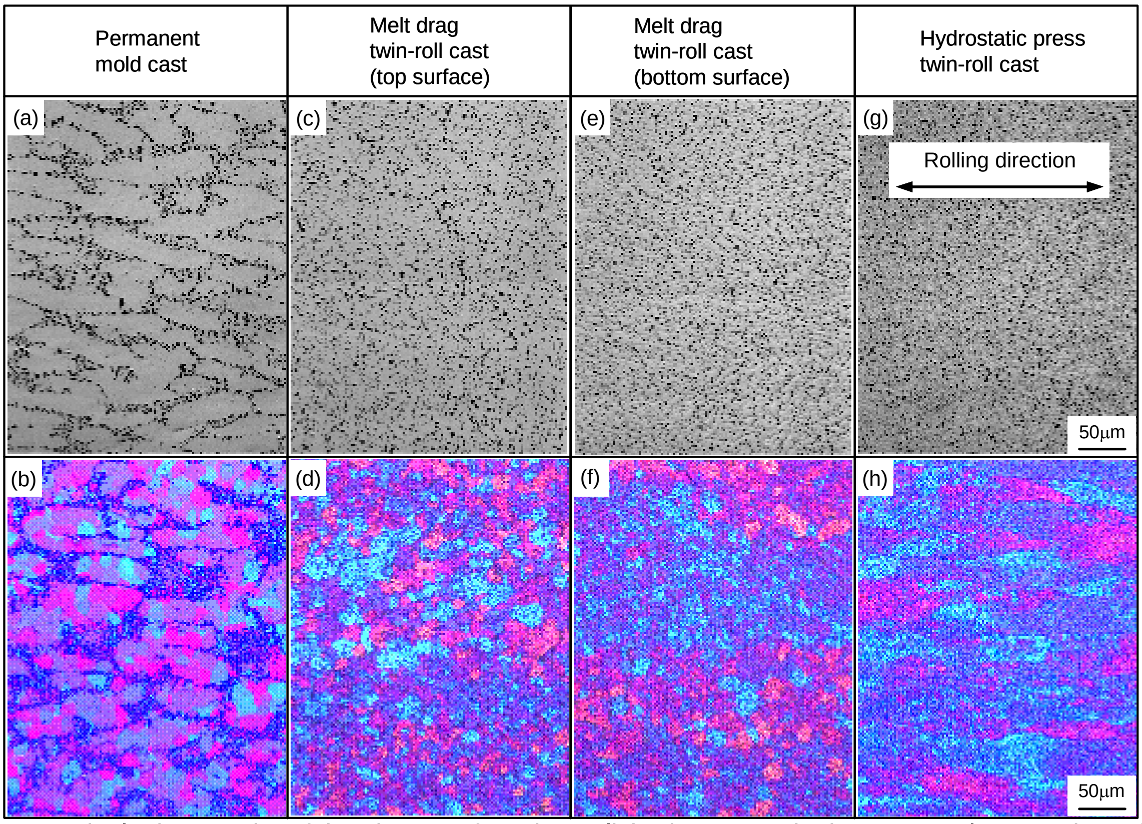
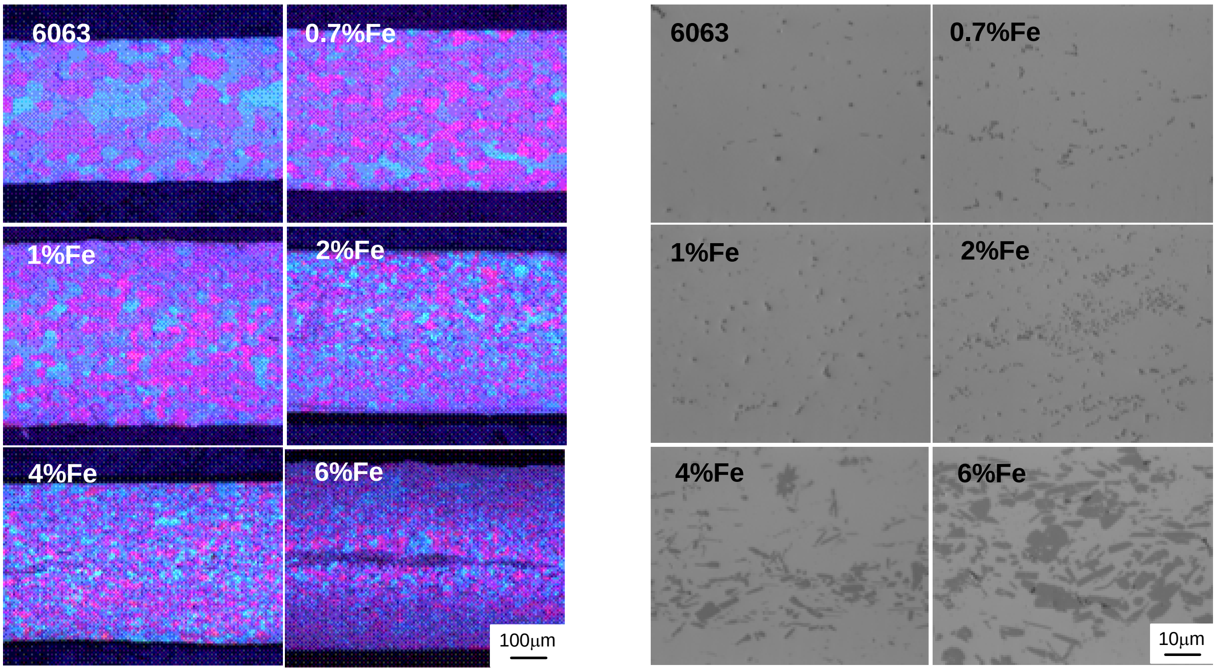


Figure 4: Optical micrographs of the sheet surface (as-polished structure in the upper column and anodized structure in the lower column). (a), (b) permanent mold cast, (c)~(f) MDTRC, and (g), (h) HPTRC.

the twin-roll cast and the permanent mold cast products. All samples exhibit recrystallized grain structure and fine and homogeneous distribution of Si particles. The large microstructural difference between the top surface and bottom surface of the MDTRC product was effectively removed in the rolled sheet. Each sheet was subjected to the 180 degree bending test. Cracking occurred only in the permanent mold cast sheet. No cracking occurred for the twin-roll cast sheet. Improved formability is considered to be mainly due to the homogeneous distribution of fine Si particles.

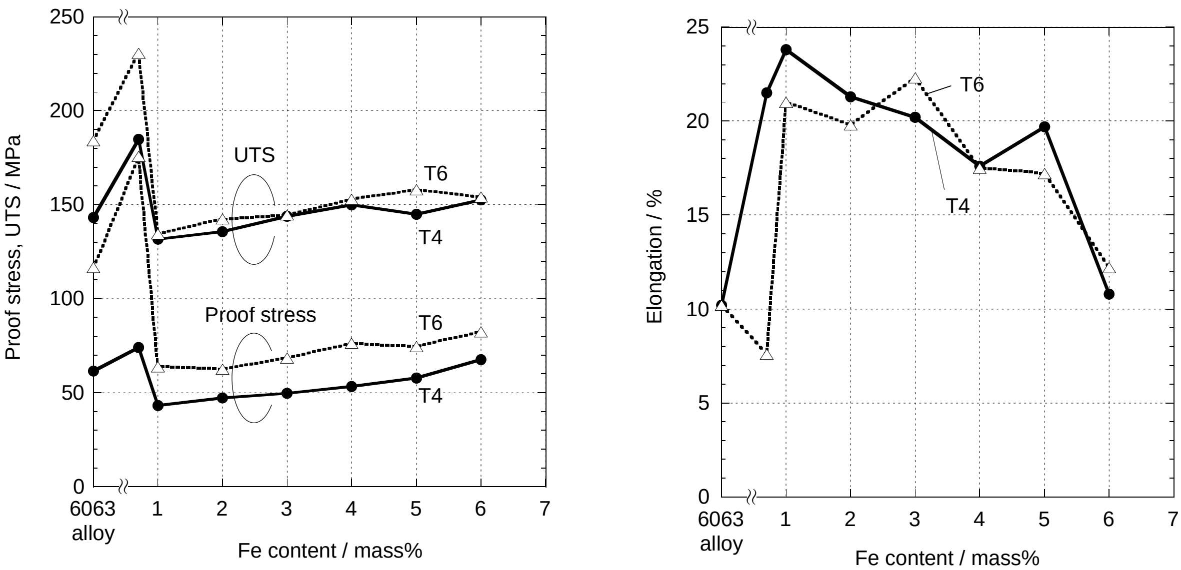
4. Microstructure and mechanical properties of the twin-roll cast 6063 alloy

The materials used in the present study is 6063 aluminum alloys with various Fe contents (0.35 (the allowable Fe content in the commercial 6063 alloy), 0.7, 1, 2, 3, 4, 5 and 6 mass%). The cast strip was fabricated at a roll speed of 60m/min using HPTRC. The thickness of the resultant cast strips were 1.5~ 2.7mm. The cooling rate of the cast strip was estimated from the relationship between DAS and cooling rates for 6063 alloys [5]. The estimated cooling rate at the near surface region is the order of 4000K/s. These twin-roll cast plates were homogenized at 813K for 7.2ks, and cold-rolled into 1mm thick sheets. After annealing at 813K for 3.6ks, they were cold-rolled again into 0.5mm thick sheets. The resultant sheets were homogenized at 813K for 7.2ks and water-quenched and then naturally-aged (T4) or artificially-aged at 433K for 21.6ks (T6).



(a) Grain structure (anodized) (b) Intermetallic compound particles (as polished)

Figure 5: Grain structure and distribution of intermetallic compound particles in the transverse cross section of the 0.5mm thick sheet (cold-rolled and heat treated).



(a) proof stress and UTS (b) elongation

Figure 6: Effect of Fe content on tensile properties of the T4 and T6 sheets.

Anodized microstructure of the transverse cross section of the 0.5mm thick sheet (cold-rolled and heat treated) are shown in Figure 5(a). All samples exhibit recrystallized grain structure. The grain size reduces with increasing Fe content. Dark-colored band structure in the mid-thickness region of the sheets with high Fe content corresponds to the segregated coarse Al-Fe-Si base intermetallic compound particles. Distribution of intermetallic compound particles in the mid-central part of the sheet is shown in Figure5(b).

Figure 6 shows tensile properties of the T4 and T6 sheets. Proof stress and UTS slightly increase as increasing Fe content in T4 specimens with more than 1%Fe content. Both proof stress and UTS for T6 specimens for the base alloy and 0.7%Fe content exhibit remarkable increase. The micro-hardness measurement found that reduced age-hardening occurred for specimens with more than 1% Fe content. These mechanical behaviors are related to the increased volume fraction of the Al-Fe-Si intermetallic compound particles. Assuming that Si is consumed in producing this compound, volume fraction of fine Mg_2Si precipitates for age-hardening will be reduced.

5. Summary

An A356 aluminum alloy was cast into a 2mm thick plate by a strip caster equipped with a pair of water-cooled rolls made of pure copper. The twin-roll cast plate exhibited fairly refined primary aluminum dendrite- and eutectic solidified structure. The estimated maximum cooling rate at the near-surface region of the plate is 4000K/s. The cast plate was cold-rolled and annealed into a 0.5mm thick sheet. The resultant sheet was subjected to the 180 degree bending test. No cracking occurred in the twin-roll product. Improved formability is considered to be due to the homogeneous distribution of fine Si particles.

The rapidly solidified cast strip of a 6063 aluminum alloy with high Fe content was cold-rolled and heat-treated to form a thin sheet. Increase in Fe content resulted in refined grain size. Detrimental effect of Fe was not evident except for reduced contribution of precipitation hardening.

Acknowledgments

This work has been supported by RISTEX of JST (Japan Science and Technology Agency) and Light Metal Education Foundation.

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