

Aluminum Material Flow in Japan and Novel Processes Utilizing Secondary Alloys

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Engineering subjects for the ideal recycling system in metals are to reduce impurity content from scrap melt, to immunize metals against impurities or make metals innocuous from impurities, and finally to replace metals with inherently recyclable metals. Through discussion in the disassembly, recovery and waste treatment stages, it is concluded that novel process technologies building high performance and/or service with low environmental burden are necessary. In particular, the secondary materials accepted for recycling should be considered to immunize their impurities by a microstructural control, since no disassemble operation fully renews them. Although the cascade of material flow is presently suitable for the aluminum recycling, a better utilization of secondary alloys is required. In order to control balanced properties with detrimental elements such as Si and Fe for developing wrought products from secondary aluminum alloys, fine microstructure with plural phases, mesocomplex structure, is one of candidates for the alloy design. Two kinds of rapid solidification processes such as new vertical semi-continuous casting equipped an adiabatic and rapid cooling mold, and high-speed twin-roll casting were demonstrated.

Keywords: *recycle, fine dispersion, microstructural control, rapid solidification, thermomechanical treatment*

1. Introduction

In view of global environmental issues, it has become essential to conserve resources and energy and to reduce environmental pollution, waste and by-products. The recycling of aluminum scrap assumes importance, since the production of primary aluminum from bauxite ore consumes a large amount of energy. Moreover, remelting of the aluminum scrap requires only several percent of the energy needed to produce the same weight of the primary aluminum.[1] The application of secondary (scrap) metals, however, has been almost limited to cast materials,[2] and the dilution by raw material has been inevitable. The question arises as to why the cascade of material flow is suitable for aluminum recycling. The products generally consist of many types of materials. Even after a bulk sorting, the elements such as Si, Fe and Mn in secondary aluminum alloys are contaminated.[3] These contaminants are detrimental to lead to very poor formability of wrought products, and their refining is difficult and higher costly. In future, however, there must be a need to explore the aluminum cast products for certain market segments of the industry. Thus, a key issue in recycling is the control of the alloying additions and impurities to retain the value of the secondary alloy.

On the other hand, the alloy compositions for casts are simplified by blending aluminum scraps. Fine microstructure with plural phases, mesocomplex structure, of the alloy design is also a key issue in recycling to control balanced properties with detrimental elements. Thus, a new technological model to be suitable for mass production has been developed to make the secondary materials which can be innocuous from the contaminants for their widespread use.[4] For promoting this model, we have proposed prototype processes for recycling products from either aluminum cast alloy [5] or wrought one [6]. To provide greater flexibility in the forging of Al-Si cast materials, a fine distribution of secondary particles in the microstructure has been achieved by employing novel processes such as rapid solidification and thermomechanical treatment. The strip casting also has potential to meet the demand of accommodating more aluminum scrap in the thin sheets such as

brazing sheet filler layer. Solidification is very rapid in twin-roll casting, leading to a fine and even distribution of secondary particles in the microstructure as well as a marked supersaturation of relatively insoluble elements.

In order to establish an upgradeable recycling design for developing wrought products from secondary aluminum alloys, analysis of aluminum material flow in Japan and development of recycle-friendly processes have been achieved.

2. Aluminum Material Flow Analysis

Input and output data of aluminum materials and products are obtained from the trade statistics reported by the Ministry of Finance, Japan, and the annual report of resources made available by the Research Institute of Economy, Trade and Industry, Japan. Statistics given by Japan Aluminum Association and Japan Aluminum Alloy Refiners Association, and a document from the Industrial Structure Council, Ministry of Economy, Trade and Industry, are also available. The statistics of the aluminum material flow in Japan for the year 2002 was summarized in the reference [4]. From 2002 both the amounts of aluminum products and collected scraps in Japan have been gradually increased as listed in Table 1.[7] From the viewpoint of material flow, the demand of scraps is estimated as 1,807,230 ton, and the amount of aluminum products may be larger than the statistics value. A large amount of scraps, however, has been exported to China as listed in Table 2.[7] The ratio of primary aluminum used to finish products is about 85% in global aluminum flow by International Aluminum Institute.[8] The ratio is about 70% in Japan, and about 20% of primary aluminum used is unknown in recycle stage if the yield rate is 60%. Therefore, details of material flow are difficult to be clear only from statistics. According to the information in 8th Aluminum Forum China, aluminum materials flow in China was summarized in the reference [9]. Its primary aluminum production of 1.318 million ton is the largest in the world as shown in Fig. 1, and amount of new scrap may be much larger than that listed in Table 1. Although the cascade of material flow is presently suitable for the aluminum recycling, a need to explore the aluminum cast products for certain market segments of the industry must arise.

Table 1 Aluminum input for products and collected aluminum scraps of 2005 in Japan and China (ton)

		Japan	China
Aluminum products (statistics)	Wrought	2,350,307	-
	Cast	530,041	-
	Die-cast	1,333,201	-
	Others	279,142	-
	Total	4,492,691	8,856,000
Collected scraps (estimated)	New scrap	542,503	420,000
	Old scrap	1,095,065	473,000
	Total	1,638,568	890,000

Table 2 Estimation of aluminum scrap export from Japan to China (ton)

Year	2000	2001	2002	2003	2004	2005	2006	2007
Export to China and Hong-Kong (statistics)	33,104	49,351	52,707	66,482	75,687	90,401	99,244	96,588
Import in China without mixed-metal (estimated)	38,241	46,454	60,977	78,983	115,749	140,411	149,617	106,258

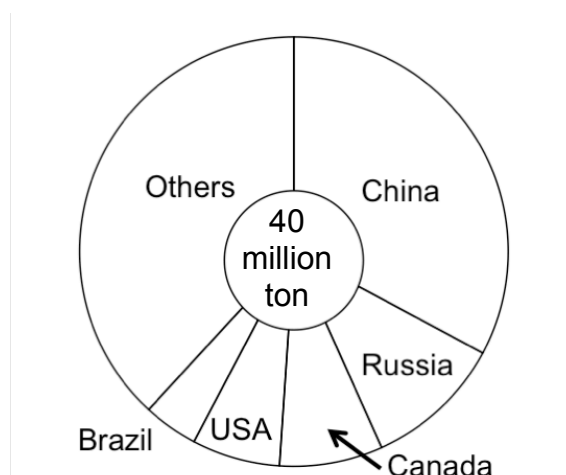


Fig. 1 Primary aluminum production in 2008.

3. Microstructural Modification with Rapid Solidification

Alloying Si, Fe, Ni and Mn, which leads to the formation of Si crystal or intermetallic compound in aluminum alloys, provides a good wear resistance, low thermal expansion, and high Young's modulus and strength at higher temperatures. The Al-Si-Fe-Ni-Mn system having multiple phases with low mutual solid solubility is effectively as an in-situ composite, and the alloys possess the advantage of recyclable material design. However, the heavy cold working cannot be applied, because it causes severe cracking in the coarse Si crystals and/or compounds. They also cause poor ductility and often give an origin of fatigue crack initiation site as well as inclusion. To improve both workability and mechanical properties, a fine microstructure with multiple phases, mesocomplex structure, is one of the candidates for an alloy design. Thus, the Si crystals and compounds must be refined to avoid the sample fracture due to their cracking. The most promising method of refining microstructures is rapid solidification. The present work deals with a new semi-continuous casting for Al-Si-X cast alloys [5] and twin-roll casting for wrought alloys [6], since they are amenable to mass production. These processes are promised to provide an up-grade solution to the recycle of secondary aluminum alloy.

3.1 Vertical Semi-continuous Casting Process

Direct chill (DC) casting process has been widely adopted to produce aluminum cast billets. However, the billets need to peel their surface followed by hot-extrusion. Then, a new vertical semi-continuous casting process using an adiabatic and rapid cooling mold has been developed to produce a billet with smooth surface for eutectic or hyper-eutectic Al-Si-Cu-Mg-(Ni, Fe, Mn) alloys.[5] This process is based on the adiabatic graphite mold casting to produce A6000 series alloys billets with a smooth surface.[10] Direct water-cooling at lower edge of graphite mold was adopted to increase cooling rate in solidification in the new process, although no cooling of the mold was done in the adiabatic graphite mold casting process. The higher casting rate to pull down the billet was, the lower surface roughness was. But there was an upper-limit of casting rate to keep molten metal in the mold as shown in Fig. 2.[5] Figure 3 shows the longitudinal section of A4032 billets with different casting rate.[5] Chill layer with periodical triangle structure appears in the slow cooling condition and results in lapping surface. The triangle structure was neither a cold-shut in the DC casting nor a ripple in the hot-top casting. It may be related with a segregation in partial slow cooling zone or re-melted zone in the mold. The increase of casting rate also makes liquid-solid interface lowered in the center part.

In those processes the cast billets directly provide forging materials and eliminate peeling and hot-extrusion process. Furthermore direct cooling of billets results in avoidance of segregation and improvement of mechanical properties. Therefore, it reduces the cost of the forging aluminum

materials approximately 20% in the case of automotive suspension arms, and lightens them. In the case of hyper-eutectic Al-Si cast billet, coalesced Si crystals or compounds were still remained in the center part, although primary Si crystals, intermetallic compounds and α dendrite structure were mostly refined under high cooling condition. A working and annealing step was installed due to increase formability of the Al-Si cast with a modification of its microstructure. An isothermal forging process with greener lubricant and precise mold technologies was developed and a prototype of motorbike engine piston was produced. The forged alloys showed higher fatigue strength and creep resistance than conventional materials at high temperatures. Fragmentation of Si crystals and compounds and their dispersion in the matrix were achieved through the forging.

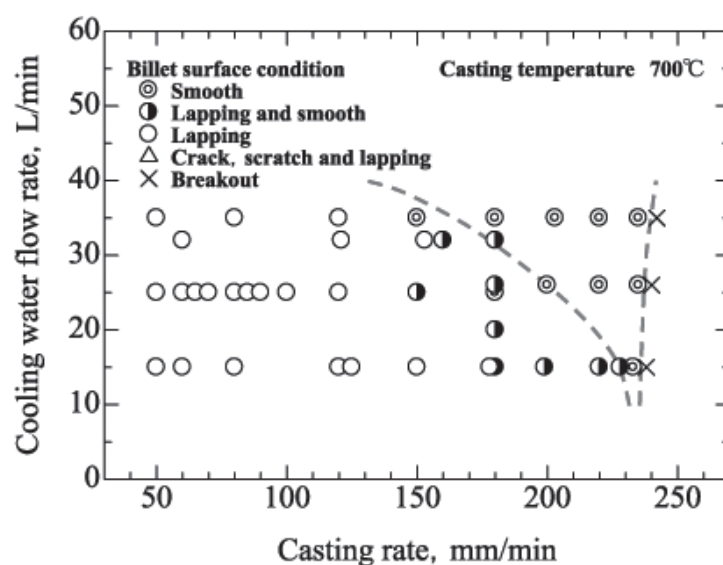


Fig. 2 Influence of casting conditions on billet surface for A4032 under the casting temperature of 973 K.

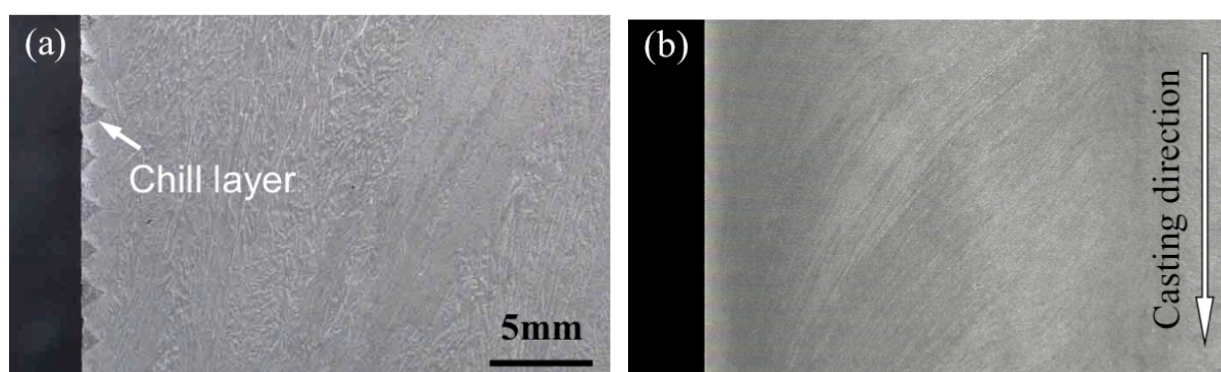


Fig. 3 Macrostructure of the A4032 HI-RCM billets with casting rate of (a) 100 mm/min and (b) 180 mm/min.

3.2 Twin-roll Casting

Influence of iron content (0.2 – 1.0 mass%) and solidification rates (3 – 1200K/s) during casting on mechanical properties of 6022 base aluminum alloys were investigated. Molten alloys were cast into about 3 mm thick plate by a vertical type high-speed twin-roll caster (HSTRC). Conventional book-type mold casting with a thickness of 5 mm and 50 mm were also fabricated for a purpose of comparison. The castings were rolled into 1 mm-thick sheets and then heat-treated. Iron content had a small effect on tensile strength of the sheet for T4 temper and after baking-treated conditions. While, elongation decreased with increasing iron content. Solidification rates also had a small effect

on the strength, though HSTRC sheets exhibited a little higher strength. This is considered to be due to higher solute content in the Al matrix of the rapidly solidified HSTRC products. Bendability was also deteriorated with the increase of iron content. It was remarkable for the sheet produced from the 50 mm-thick plate with the low solidification rate. Improved bendability of the sheets fabricated from high solidification rate products (HSTRC and 5 mm-thick plate) was considered to be mainly due to the finer second phase particles.

4. Summary

Although the cascade of material flow is presently suitable for the aluminum recycling, a better utilization of secondary alloys must be required in future. Two kinds of rapid solidification processes such as vertical semi-continuous casting equipped an adiabatic and rapid cooling mold, and high-speed twin-roll casting have been proposed to produce an aluminum wrought product with fine microstructure. The semi-continuous cast is suitable to produce an extruded or forged product. The twin-roll casting directly produces a thin sheet. In both methods, microstructural refinement, good ductility and balanced properties of aluminum secondary alloys can be designed with a combination of thermomechanical treatment.

Acknowledgement

This study has carried out by the projects “Development of civic model on materials technology for recycling-based society” in the studies on sustainable society at Research Institute of Science and Technology for Society, “Novel process and product development with precise forging of Al-Si hyper-eutectic alloys towards high performance and low environmental load” in the regional research and development resources utilization program, “Development of recyclable aluminum materials: casting process and mechanical properties” in the challenge research program, and “Production of aluminum window frame and its aluminum used in China”. Financial supports from Japan Science and Technology Agency, The Light Metal Educational Foundation and TOSTEM Foundation for Constructional Materials Industry Promotion are gratefully acknowledged.

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