PAPER

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Processing of Recycled AA6111 Aluminium Alloy from Two Different Feedstock of Aluminium Metal Scraps

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Recycling of scrap Al requires 5% of energy and saves 95% of CO_2 emission as compared to the production of primary Al. Hence, there is an increasing demand to exploit the use of recycled Al alloys to reduce energy consumption and carbon footprint associated with the manufacturing processes. However, a major technical challenge to the widespread use of recycled Al is the presence of high impurity content such as Fe, which can severely deteriorate its mechanical performance. Hence, the development of a new technology is crucial to the production of good quality recycled Al alloys from the metal scrap. A melt conditioned direct chill (MC–DC) technology has been developed at BCAST which is based on the application of a high shear dispersive mixer in the molten alloy prior to solidification to produce a fine as-cast microstructure with reduced segregation in the absence of any grain refiners. This study is concerned with the microstructure/properties of recycled AA6111 Al alloy billets produced from two different metal scraps including Incinerator Bottom Ash (BA) and Old Rolled Taint Tabor (TT), using a combination of the novel MC–DC, together with a combination of hot extrusion, cold rolling and heat treatment processes.

The production of recycled AA6111 aluminium alloy blanks with good mechanical performance comparable to primary AA6111 alloy has been demonstrated via melt conditioned DC casting of metal scraps together with downstream thermomechanical processing using extrusion and rolling operation. Sample processed from Old Rolled Taint Tabor (TT) metal scraps gives similar alloy composition and mechanical performance after T6 heat treatment. However, sample processed from Incinerator Bottom Ash (BA) metal scrap consisted of relatively high amount of Si content, leading to finer grain structure and marginally better mechanical performance in T4 condition.

Key Words: recycled aluminium alloy, casting, extrusion, microstructure, properties

1 Introduction

Aluminium alloys have low density (3 times lighter than steel), high corrosion resistance and a good combination of physical and mechanical properties[1]. This makes aluminium alloys particularly attractive for applications in the transport industry, particularly in the automotive and aerospace sectors. Since 1950, the demand of aluminium products has increased by 30–fold to 45 million tonnes per year, with forecasts predicting this exceptional growth to continue and reach 2–3 times the current demand by 2050[2]. This fast growth is mainly driven by lightweight vehicle construction in the automotive industry for improved fuel economy and reduced CO_2 emission.

However, the production of primary aluminium from metal extraction and refining processes uses 3.5% of global electricity and causes 1% of global CO_2 emissions. The need to reach 50% cut in emissions by 2050 against a growing demand of Al would require at least a 75% reduction in CO_2 emissions per tonne of aluminium produced[3], which is a challenging prospect for primary aluminium. Alternatively, recycling of scrap Al requires 5% of energy and saves 95% of CO_2 emission as compared to the production of primary aluminium[4]. Hence, there is an increasing demand to exploit the use of recycled Al alloys to reduce energy consumption and carbon footprint associated with the manufacturing processes. However, a major technical challenge to the widespread use of recycled aluminium is the presence of high impurity content such as Fe, which can severely deteriorate its mechanical performance due to the presence of Fe intermetallic platelets. Hence, the de-

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velopment of a new technology is crucial to the production of good quality recycled Al alloys from the metal scrap.

A melt conditioned direct chill (MC–DC) technology has been developed at BCAST, Brunel University London which is based on the application of a high shear dispersive mixer in the molten alloy prior to solidification to produce a fine as-cast microstructure with reduced segregation in the absence of any grain refiners, as well as suppression of irregular growth of intermetallic phase[5].

The study is concerned with the microstructure/properties of recycled AA6111 Al–alloy billets produced from two different sources of metal scraps using a combination of the novel MC–DC, together with a combination of hot extrusion, cold rolling and heat treatment processes.

2 Method

2.1 Materials & Processing routes

Incinerator Bottom Ash (BA) and Old Rolled Taint Tabor (TT) aluminium scraps were used as initial feedstocks in the preparation recycled AA6111 alloy billets with 152 mm in diameter. MC–DC casting of metal scraps was performed by shearing the molten aluminium scraps using a high-shear device[5], operated at a rotor speed of 2000RPM at 648℃ in the sump. The MC–DC billet was homogenized at 530℃ and extruded at 480℃ and 4 m/min, to produce a blank of 120 mm wide and 4 mm thick. The blank thickness was then reduced to 3.5 mm by cold rolling at room temperature. They were then subjected solution treatment at 535℃ for 10 mins and followed by water quenching to form supersaturated solid solution. As–quenched samples were heat treated in T4 (eg. natural aging for 7 days) and T6 (eg. 180℃ for 11 hours) conditions.

Table 1 Composition of recycled AA6111 prepared by MC–DC casting of BA and TT grade feedstock.

	AA6111 (target)	BA	TT
Si	0.63	1.17	0.74
Mg	0.75	0.75	0.72
Cu	0.75	0.76	0.8
Fe	0.25	0.36	0.4
Mn	0.2	0.39	0.21
Cr	<0.08	0.05	0.03
Zn	<0.05	0.26	0.26
Ti	<0.08	0.03	0.01
Al	Bal	Bal	Bal

2.2 Material characterisation

Each recycled feedstock after processing by MC–DC casting, extrusion and cold rolling was subjected to metallographic preparation for microstructural characterisation using a combination of Zeiss Supra 35 scanning electron microscope (SEM) and JOEL 2100F transmission electron microcope (TEM). The dimensions of the rectangular subsize tensile test specimen were based on ASTM E 8M. Tensile tests were carried on three specimens at least from the longitudinal section for all processing conditions.

3 Results and Discussion

Fig. 1 show the centre of recycled AA6111 billet processed by direct chill casting of BA feedstock with grain refiner but without high-shear melt conditioning. **Figs 2** and **3** show typical as-cast grain structures obtained from

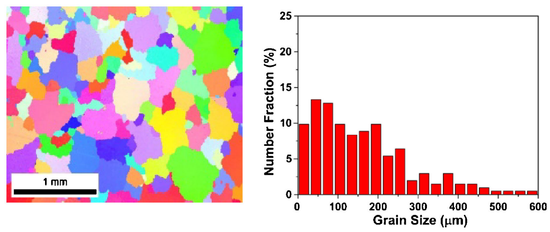

Fig. 1 EBSD micrograph of DC A6111 recycled alloy processed without melt-conditioning from BA feedstock with corresponding size distribution

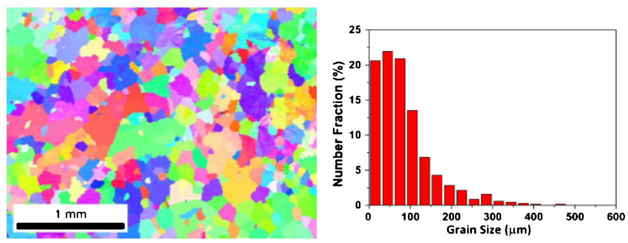

Fig. 2 EBSD micrograph of MC–DC A6111 recycled alloy from BA feedstock with corresponding size distribution.

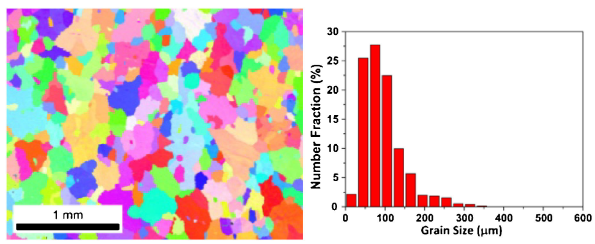

Fig. 3 EBSD micrograph of MC–DC A6111 recycled alloy made from TT feedstock with corresponding size distribution.

the centre of recycled AA6111 billets processed by MC–DC from BA and TT feedstocks, respectively. The grain structure is found to be coarser without melt-conditioning. However, the microstructure of recycled A6111 alloy processed by MC–DC from BA feedstock, consisted of higher fraction of fine grains (<100 μm) than those processed from TT feedstock.

The as-cast microstructure of recycled Al alloy processed from TT and BA feedstock consisted of α–Al matrix with different intermetallic phases, as shown in **Figs 4** and **6**. These intermetallic phases were identified as Q–phase ($Al_5Cu_2Mg_8Si_6$), Al_5FeSi and α–$Al_{15}Si_2(Fe, Mn)_3$ intermetallics, as shown in **Figs 5** and **7**. The Al_5FeSi and α–$Al_{15}Si_2(Fe, Mn)_3$ correspond to the needle-like β–Fe and Chinese script α–Fe phases[6], respectively. Both blocky and spherical morphology[7] of $Al_5Cu_2Mg_8Si_6$ phase were found in samples processed from TT to BA feedstocks. However, the relatively high Cu content in sample processed from TT feedstock led to the formation of Al_2Cu phase, as shown in Fig. 5b.

After extrusion, cold rolling and T6 heat treatment processes, the resultant microstructure of MC–DC A6111 recycled alloy, consisted of a mixture of α–Al matrix, Fe–rich intermetallic and Mg_2Si particles, together with strengthening precipitates, as shown in **Figs. 8**(a–b). The average sizes of Fe–rich intermetallic and Mg_2Si particles present in the annealed recycled A6111 alloy processed by melt conditioning method are found to be 1.5 μm and 0.9 μm, respectively. They are similar as compared with those processed by conventional route.

The tensile properties of sample processed from BA

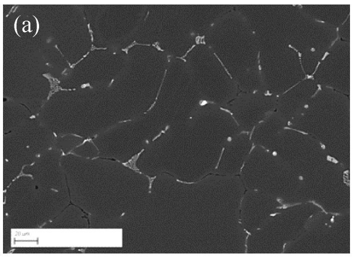

Fig. 4 SEM micrograph of MC–DC A6111 recycled alloy made from TT feedstock.

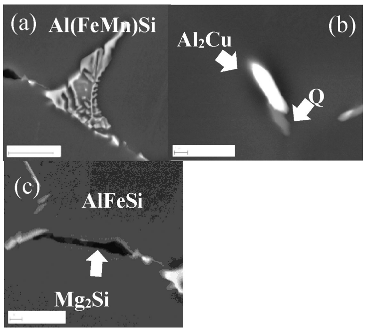

Fig. 5 Phases identified in MC–DC A6111 recycled alloy made from TT feedstock.

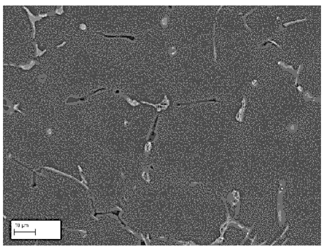

Fig. 6 SEM micrograph of MC–DC A6111 recycled alloy made from BA feedstock.

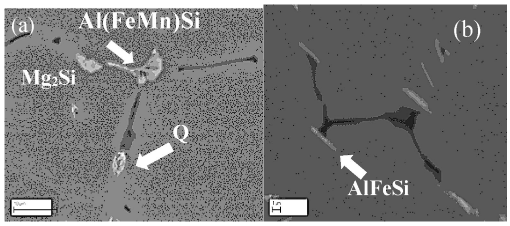

Fig. 7 Phases identified in MC–DC A6111 recycled alloy made from BA feedstock.

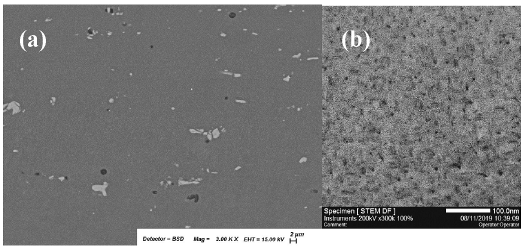

Fig. 8 (a) SEM and (b) TEM micrographs of MC–DC A6111 recycled alloy processed from BA after extrusion, cold rolling and T6 heat treatment.

Table 2 Tensile properties of recycled Al alloy before and after heat treatment.

Feedstock	Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
TT	As-rolled	192±4	203±3	8.5±2.1
BA	As-rolled	208±2	215±2	7.0±1.4
TT	T4	143±1	294±5	26.0±1.2
BA	T4	172±1	323±2	30.5±0.5
TT	T6	312±2	350±3	13.7±0.6
BA	T6	277±3	331±0	18.0±1.8

feedstock are better than those from TT feedstock for both as-rolled and T4 conditions, as shown in **Table 2**. In addition, samples processed from both TT and BA feedstocks in T4 condition, exhibit tensile properties comparable to those[8] of primary AA6111–T4 (eg. yield strength of 172, tensile strength of 290 Ma and elongation of 28%). However, the tensile properties of sample processed from TT feedstock exceed those from BA feedstock after T6 heat treatment. This may be because the peak ageing condition has not been achieved in the sample processed from BA feedstock as it has relatively high Si content as compared to that of sample processed from TT feedstock. Whereas the sample processed from TT feedstock after T6 treatment gives tensile properties comparable to primary AA6111 at T6 condition published in literature[9] (eg. yield strength of 299 MPa, tensile strength of 360 MPa and elongation of 11.9%).

4 Conclusions

Recycled AA6111 alloy has been successfully produced from two different grade of metal scraps (eg. TT and BA) by melt conditioned direct chill (MC–DC) casting technology without the need of any grain refiners. The recycled aluminium alloy processed from TT feedstock has composition closer to AA6111 which yields tensile properties comparable to primary AA6111–T6. The Si–rich recycled aluminium alloy processed from BA stock offers the potential of finer grain structure than that from TT, but the T6 condition needs further optimization to improve its mechanical performance. Finally, the application of the high shear melt conditioning technology together with conventional hot extrusion and cold rolling processes has enabled the production of recycled Al–based alloy from metal scraps to give promising mechanical properties at industrial scale without the need for any chemical grain refiners.

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