Effect of Minor Elements on Castability, Microstructure and Mechanical Properties of Recycled Aluminium Alloys

Bruno Robert Mose

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ABSTRACT

As part of the wider effort to improve the performance of cast aluminium alloys, this research set out to investigate the effect of minor elements (Fe, Mn, Cr, Sr, Sb and Ti-B based grain refiners) on castability (fluidity and porosity formation), microstructure and mechanical properties (UTS, percentage elongation, impact strength and Brinell hardness) of recycled aluminium alloys. A survey of the local aluminium foundries was also conducted to establish the prevailing aluminium casting practices such as recycling methods, casting design, melt treatment and quality control aspects, and whether these practices are effective in making quality castings.

Fluidity tests were conducted using CO_2/sodium silicate bonded spiral sand moulds. Fluidity was indicated by the length the molten metal ran before being stopped by solidification. Specimens for mechanical tests and porosity analysis were prepared from castings obtained from a permanent mould. For tensile tests, specimens were prepared from the sound section in accordance to the ASTM B108-82b while those for impact tests were prepared in accordance to ASTM E-23 standards. Hardness test specimens were polished using fine SiC paper to remove any machining marks on the surface before indentation. Fracture surface specimens were prepared in accordance to ASTM E-8M standards to help reveal features contributing to failure during tensile tests. Metallographic specimens were also polished using SiC papers with a fine polish being performed on grinding wheels using 0.25μm diamond paste, and to aid in identification of the phases present in the microstructure, the samples were deep

etched in a solution of 10% NaOH in distilled water. A T6 heat treatment procedure was performed on specimens for mechanical tests to enable make comparison with as cast specimens. Porosity analysis was performed using density measurement method. To collect data for the survey, a questionnaire was designed with test items being administered both orally and in some cases foundrymen were requested to fill them.

Results from fluidity tests indicated that fluidity increased by 21% when Fe was raised to the critical content of 0.48% for LM25. A combination of 0.3%Mn or 0.6%Cr with 0.6%Fe in LM25, resulted in a fluidity increase of 13% and 8%, respectively compared to the base alloy, but a combination of 0.6%Fe, 0.3%Mn and 0.2%Cr decreased the fluidity by 9%. A 34% increase in fluidity was observed when the Fe content in LM27 was raised from 0.41% to the critical level of 0.6%Fe with further increase when Mn was raised to 0.3%Mn. Addition of 0.015%Sr and 0.02%Sr increased the fluidity of LM25 and LM27 by 9% and 21% respectively. Furthermore, a 0.28% Al-5Ti-1B grain refiner addition decreased the fluidity of LM 25 and LM27 by 2% and 19% respectively.

The results from porosity analysis indicated that the volume percent porosity in LM13-type base alloy was 1.6%. With addition of Sr at levels of 0.02% and 0.05% the volume percent porosity increased to 2.9% and 2.6% respectively. When individual additions of 0.53%Mn and 1.06%Cr were made to the alloy, the volume percent porosity reduced to 0.6% and 0.4% respectively. It was further noted that a combined addition of 0.3%Mn together with 0.2%Cr reduced the volume percent porosity of this alloy to 1.0%. Other reductions in porosity were observed when 0.53%Mn was added in combination with each of 0.02%Sr, 0.05%Sr and 0.2%Sb. Addition of 0.02%Sr together with 0.28%Al-5Ti-1B grain refiner slightly reduced the volume percent porosity of the base alloy to 1.4%.

Microstructural results showed that the as cast microstructure of LM13-type alloy consisted of a structure with coarse Si particles, large AlCuNi phases in addition to Al_2Cu phases on the α-Al matrix. Addition of 0.02%Sr to the alloy led to partial modification of the eutectic Si particles while addition of 0.05%Sr led to full modification of the eutectic Si. Separate additions of 0.53%Mn and 1.06%Cr transformed the flake-like AlCuNi structures to Chinese script morphology. It was also noted that the effect of heat treatment was spheroidization and coarsening of the Si particles. At the same time, there was fragmentation of intermetallic particles.

Results from UTS and % elongation revealed that with addition of Sr at levels of 0.02% and 0.05% the average values of UTS increased by 4% and 5% respectively in as cast while it increased by 6% and 8% in T6. Moreover, with the 0.02%Sr and 0.05%Sr addition the % elongation increased by 22% and 17% in as cast and by 24% for each level of Sr in T6. When individual additions of 0.53%Mn and 1.06%Cr were made, improvements of 13% and 18% in the UTS were recorded in as cast condition while in T6 condition the improvements were 15% and 16%. With these additions, the % elongation of the alloy increased by 35% and 61% in as cast and by 38% and 43% in T6.

The results from hardness and impact tests indicated that addition of Sr improved the Brinell hardness and impact strength of the LM13-type alloy in both as cast and T6 condition. On the other hand, improvements in these properties in as cast and in T6 condition were recorded when individual additions of 0.53%Mn and 1.06%Cr were made to the alloy. Furthermore, improvements in the Brinell hardness and impact strength of the alloy were recorded when each of 0.2%Sb, 0.02%Sr and 0.05% Sr was combined with 0.53%Mn both in as cast and in T6 condition.

Results from the survey demonstrated that nearly all the foundries visited operate at about 40% capacity utilization. In addition, control of process parameters was limited, with methods being non competitive and quality control aspects being hardly adequate. Use of alloying elements (additives) as a means to improve properties of castings was seldom utilized, leave alone knowledge of existence of such additives. Out of 45 companies visited 98% were not using additives to control the properties of castings. This in turn resulted in production of low quality and unreliable castings. Noting that some companies visited supply their products to the international market, the majority would find themselves disadvantaged if it turns out that their products need to meet certain standards that call for use of additives. It was therefore recommended that collaborative effort be made between research institutions and industry as well as the government as one of the basic steps towards improvement of the casting practice and enhancement of capacity utilization in local foundries.

Overall the results indicate that use of minor alloying elements can have significant effects on castability, microstructure and mechanical properties of recycled Al alloys. Addition of Fe to the critical Fe level to LM25 and LM27 type alloys gave higher fluidity results compared to Fe levels below and above this level. It was also established that modification due to 0.02%Sr addition was not the same as that due to 0.05%Sr addition. A 0.02%Sr addition caused partial modification while 0.05% caused full modification. Addition of high levels of Cr (not applied by most researchers in the past for fear of sludge formation) to LM13 type alloy led to very superior mechanical properties of the alloy. Micrographs from samples with Cr addition did not show formation of sludge. A survey of the local foundries in the major towns of Nairobi, Mombasa and Nakuru indicated that the recycling methods, casting design, melt treatment and quality control used in these foundries were hardly adequate to ensure production of premium castings.