Foaming of aluminium alloys derived from scrap

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Abstract

Aluminium alloys made from machining chips that have been heat treated and re-melted, have been successfully foamed (after the addition of TiH_2) using processes analogous to both the “Alporas” and “Formgrip” methods. The high oxygen contents associated with the swarf (0.11wt.% for the as-received material, increasing to >0.5wt.% after conditioning) results in large fractions of both clustered and dispersed oxide films in the melt. It is these films that enhance the “foamability” of this material. Through additional alloying with Mg and holding in the liquid state to allow reaction to take place, fragmentation and wetting of the oxides occurs and foams with low densities (< 0.3 g/ cm^3), good pore structures and good stability were obtained. The use of scrap material, without costly or embrittling additives, offers a low cost route to the manufacture of high quality foams.

1 Introduction

Making aluminium foams entirely from scrap is attractive due to the cost savings offered by a low-cost matrix and the potential for eliminating expensive and embrittling foam-stabilising additives. For particular alloys, sourced carefully, reproducibility in form, composition and cleanliness can be achieved, in quantities that are commensurate with those required for niche products such as Al foams. For Al in the form of chippings or turnings from machining processes, powder metallurgy (PM) or liquid routes (analogous to the Alulight or Alporas methods respectively) to make metal foams could be adopted. However, in reality alloy turnings have high aspect ratios, pack very poorly and have low compressibility, making foamable precursors difficult to manufacture by PM, favouring foam production via a liquid route.

Remelted Al scrap in the form of used beverage cans, has been used,[1] in conjunction with TiH_2 blowing agent, to produce Al foam. It is reported that the scrap, via the oxides introduced from their surfaces, acts as a viscosity thickener, aiding foaming.[1] Highly distorted cell structures were, however, observed and attributed to the inhomogeneous distributions of the introduced oxides. It was concluded that the agglomerated oxide particles introduced could not act as a foam stabiliser. More recently Alcoa report the development of a commercial Al foam derived from scrap material made by a liquid route using $CaCO_3$ as a foaming agent.[2] The aim of the present study is to undertake a preliminary investigation into the expansion, structure and stability of foams made from 100% Al alloy scrap produced via a liquid route.

2 Experimental Procedure

The scrap used was swarf in the form of mm-sized chips, a by-product of the machining of LM26, an alloy commonly used for making automotive castings. The shape of this swarf is shown in Fig. 1 along with the approximate composition measured by optical emission spectroscopy (OES). The approximate melting range for the alloy is 530-580 °C, as measured by differential scanning calorimetry. The scrap was heat treated at 500°C in air for 24 h in an effort to increase the oxide content.

Processing of the scrap into ingots was performed by charging a crucible (preheated to 750 °C) with scrap. After melting of the scrap (which takes roughly 30 min) the charge needed to be vigorously stirred to amalgamate the individual, molten chips. Given the poor packing of the swarf, this produced only a partially filled crucible, which is why the procedure was repeated twice to produce a full charge. After the final swarf addition and stirring, 0, 1 or 2 wt.% Mg additions were made via an Al-Mg master alloy, after which the melt was kept at temperature for 4 h to “condition” the melt. After this final step, the metal was cast into a steel mould. Samples were taken for metallographic and oxygen analysis and analysis by X-ray diffraction (XRD).

Element	**wt.%**
Si	10.50
Cu	1.60
Fe	1.20
Mn	0.29
Mg	0.13
Zn	1.10
Al	balance

Figure 1. Photograph of the swarf chips and chemical composition (measured by OES).

The torque required to stir the molten scrap alloys was measured using an apparatus resembling a concentric cylinder viscometer. In this arrangement, a 70 mm OD graphite bob was rotated at 1000 rpm in a cylindrical crucible with an internal diameter of 87 mm. The melt temperature was held at 700 ± 2 °C and the volume of metal and bob immersion depth were kept constant. The stirring torque was used as an indication of the viscosity of the alloy (since for this type of setup the stirring torque is directly proportional to the viscosity) and viscosity was considered a measure for the effect of scrap and elemental additions.

Foams were made by processes analogous to both the “Alporas” and “Formgrip” methods. In the Alporas-type method, 1.6 wt.% of TiH_2 was added to the molten alloy at 700 °C, stirred and left to foam for either 100 or 140 s before cooling. The pore and cell wall structures for these foams were examined using optical microscopy and 3D X-ray tomography as explained in [3]. Foam densities were measured using Archimedes’ method, with the surface skins still intact. Foamable precursors made by the Formgrip-type method using 1.5 wt.% of heat treated TiH_2 were reheated and foamed at 700°C for 600 s whilst performing insitu 2D X-ray radioscopy. These foaming methods are similar to those reported in [4,5].

3 Results and Discussion

The oxygen content measured in the as-received swarf was 0.11 ± 0.01 wt.%, increasing to 0.53 ± 0.05 wt.% after heat treatment. If we assume that all the oxygen is contained in Al_2O_3, this corresponds to 0.23 and 1.13 wt.% Al_2O_3 respectively. Typical oxygen levels in the corresponding virgin base alloy were < 0.03 wt.%. Since the swarf is heated over a prolonged period in loose form in the crucible, the oxygen level in the cast re-melted scrap alloy was also measured, and found to be 0.60 ± 0.07 wt.% (1.27 wt.% Al_2O_3). The oxide levels in this study are similar to those in foamable compacts made by a powder route, which are typically up to 1 wt.%.[6, 7]

Fig. 2 shows the typical structures of the oxides introduced into the alloy, originating from the surfaces of the swarf. The oxides are thin sheets and are highly tangled, exacerbated by melt stirring. Most commonly they exist as oxide clusters, varying in size, but normally exceeding 100 μm in diameter. Although very difficult to quantify, Fig. 2 also shows that the oxides appear to become more fragmented after alloying with Mg. XRD detected the formation of MgO in melts to which Mg was added (it was not clear whether spinel ($MgAl_2O_4$) is also present, as this might also be formed[8, 9]). If the estimated 1.27 wt.% Al_2O_3 reacts with Mg to form MgO, then 0.9 wt.% Mg is required for 100% conversion, much higher than that which is present in the re-melted scrap without Mg addition.

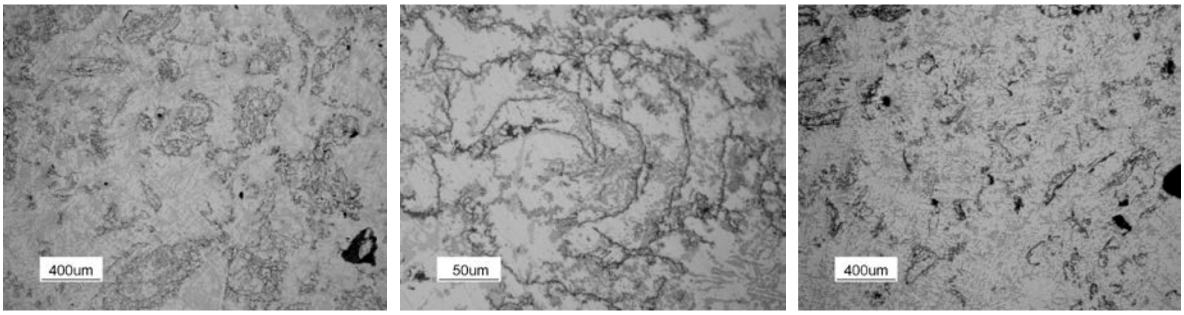
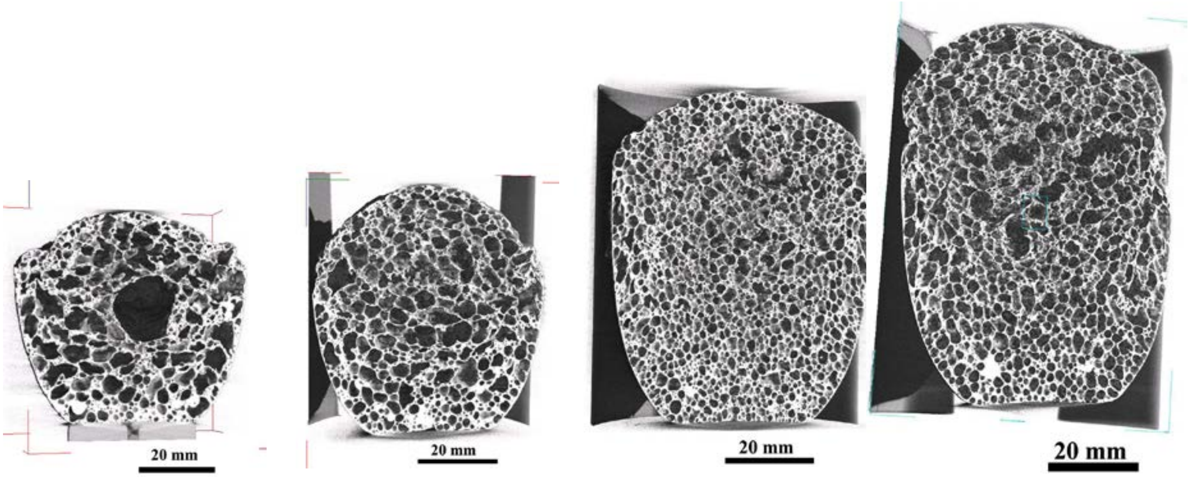


Figure 2 Optical micrographs of oxide films and clusters in re-melted scrap alloys (left and centre) and with 2wt.% Mg addition (right).

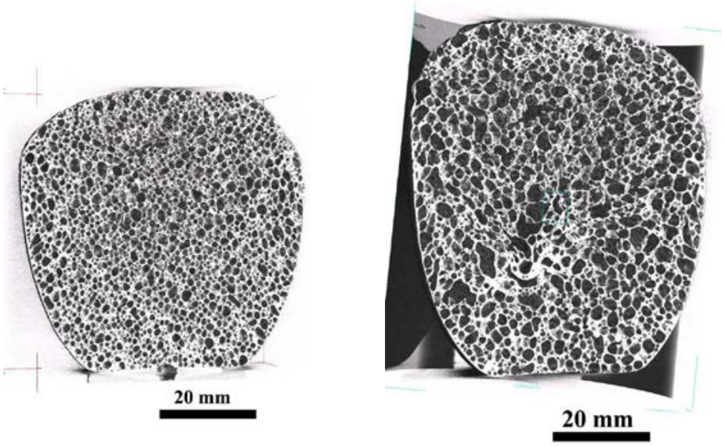
The torque required to stir the re-melted scrap alloy was 1.40 N cm, twice the value measured for stirring the equivalent virgin alloy. This increase is similar to that observed by other researchers when adding “thickeners” to produce Al foams,[10] but is below the typical fivefold increase observed for Ca additions to Al in the Alporas process.[11] 1 and 2 wt.% Mg additions reduce the stirring torque to 1.25 and 1.14 N cm respectively, a larger decrease than observed when adding 2 wt.% Mg to the virgin alloy (decreasing from 0.70 to 0.67 N cm).

Although speculative at this stage, it is thought that in addition to the inherent reduction in viscosity with Mg addition, the concomitant fragmentation of the oxide clusters (affected by stirring of the reacted and embrittled Al_2O_3/MgO films[12]) also decreases the viscosity. It should be noted that unlike similar studies that add thickening agents,[10, 11] in this system, the torque was constant throughout the 60 min stirring period, indicating that any reactions affecting the viscosity had already occurred during the “conditioning” period.

The combined observations from the foaming trials, presented in Fig. 3, 4 and 5, show that for the re-melted scrap, the alloy expands well initially but then steadily collapses. The density attained after foaming for 140 s is quite low, at 0.42 g/ cm^3, but the pore structure is coarse and irregular with signs of drainage at the base of the foam. Mg additions decrease the velocity but significantly improve the magnitude of the foam expansion, achieving densities of 0.29 and 0.32 g/ cm^3 after holding for 140 s with 1 and 2 wt.% additions respectively (with the skin removed these foams will have similar densities to Alporas foams, typically 0.18 - 0.24 g/ cm^3). The pore structures with Mg are also reasonably uniform as can be observed in the tomographic reconstructions in Fig. 3 for different Mg contents and foaming times. Fig. 4 shows a sequence of in-situ X-ray radiographs of foam development and the corresponding temperature and expansion course are shown in Fig. 5. There is no evidence for drainage or collapse. Shrinkage only occurs during solidification of the foam. 1 wt.% Mg addition appears to be optimum for maximising the foam expansion as this is sufficient to allow complete reaction of the oxides to form MgO. There appears to be no benefit in adding excess Mg.



Scrap, 100s Scrap, 140s Scrap + 1 wt.% Mg, 100s Scrap + 1 wt.% Mg, 140s



Scrap + 2 wt.% Mg, 100s Scrap + 2 wt.% Mg, 140s

Figure 3 Remelted scrap foam structures (from CT) as a function of Mg content and foaming time at 700°C.

Optical micrographs in Fig. 6 and 7 show the cell structures, in more detail, along with the morphology and location of the oxides. The introduction of oxides clearly enables a foam to be produced, but the expansion is short-lived unless Mg is added. Without additional Mg, the prevalence of large oxide clusters is high and these highly tangled structures are unlikely to contribute to stabilisation of the foam structure (as was concluded in [1]). Although smaller oxides are also observed, and the melt contains some Mg, foam-stabilisation is not effective, leading to irregular pore geometries, drainage of liquid and foam collapse. It is proposed that with higher Mg levels, the oxides (which have reacted to form MgO and possibly spinel) are better wetted by the molten metal and as a result, are more effective at stabilising the foam, resulting in large foam expansions and little or no drainage.[5,13,14]

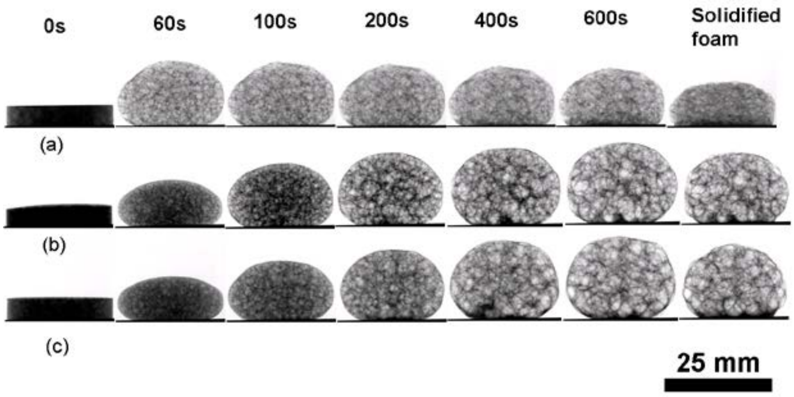


Figure 4 Insitu 2D radioscopy of “Formgrip” precursors a) re-melted scrap, b) scrap + 1 wt.% and c) scrap + 2 wt.% Mg.

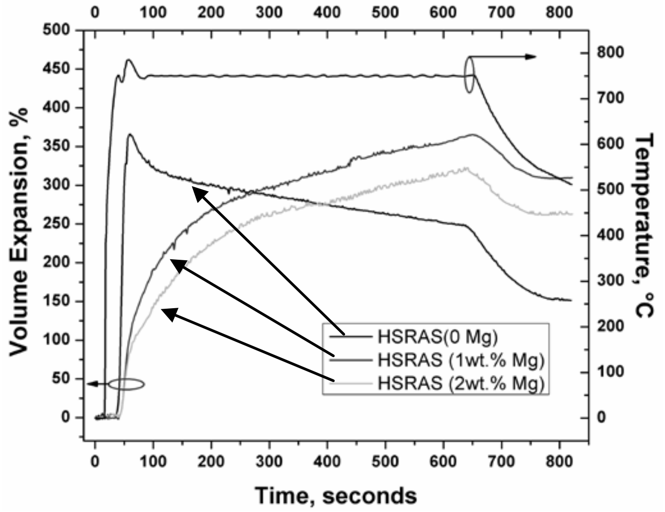


Figure 5 Expansion-time plots corresponding to insitu 2D radioscopy images in Figure 4.

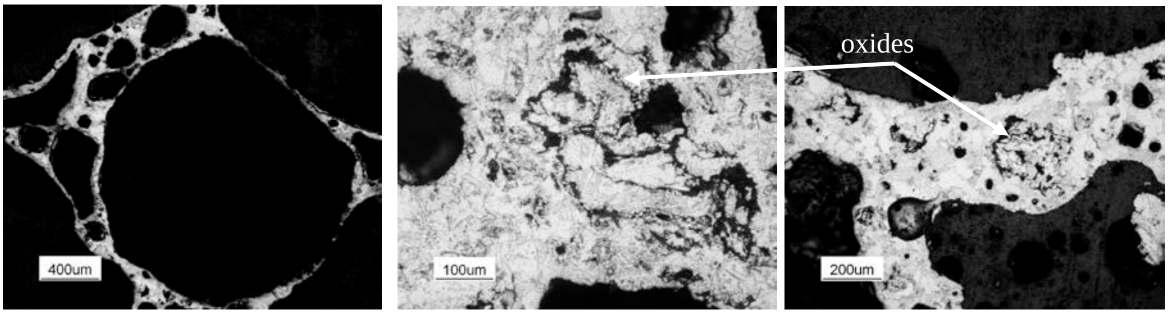


Figure 6 Optical micrographs of cell wall structures for foams made from re-melted scrap.

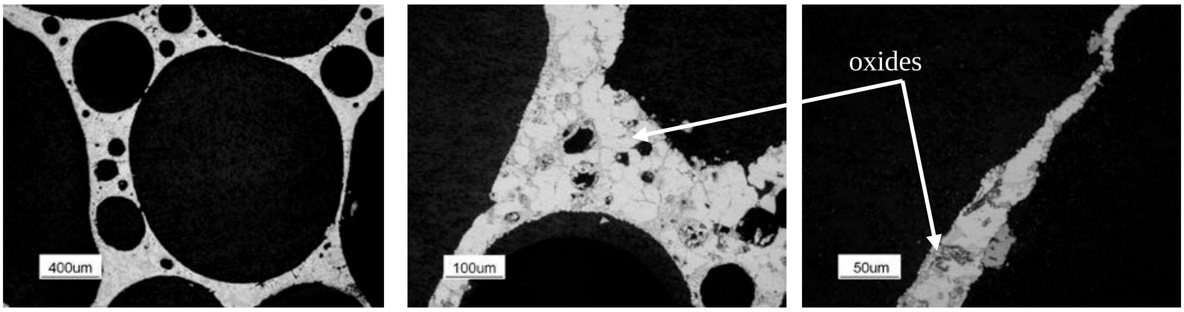


Figure 7 Optical micrographs of cell wall structures for foams made from scrap containing 2 wt.% Mg.

The stabilisation mechanism is thought to be shared with foams made by a powder route, where the dispersed oxide films increase the bulk viscosity and form networks that are barriers to the passage of the melt, slowing down the vertical motion of liquid metal induced by drainage.[7,15] Although the addition of Mg was observed to decrease the bulk melt viscosity, it is thought that the resultant formation of wetted oxides at the liquid-gas interface will increase the surface viscosity, inhibiting the flow of liquid, thereby improving the stability of the foam structure, but in the same way slowing down the foam expansion.

4 Conclusions

- Aluminium alloys made from machining chips that have been heat treated and re-melted, have been successfully foamed after the addition of TiH_2.
- Through additional alloying with Mg, foams with low densities (< 0.3 g/ cm^3), good pore structures and good stability were obtained.
- Foam formation and stabilisation is affected through the introduction of oxide films associated with the scrap. Although the tendency for these oxides is to form clusters, by alloying with Mg and holding in the liquid state to allow reaction to take place, fragmentation and wetting of the oxides occurs.

5 References

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