A. JUAREZ-HERNANDEZ, R. BENAVIDES-TREVIÑO, O. BARCEINAS-SANCHEZ, M. HERNANDEZ-RODRIGUEZ, R. ALMAGUER

ISSN 0543-5846
METABK 53(2) 218-220 (2014)
UDC – UDK 669.715:621.694.669.786:539.377=111

STUDY OF PROCESS PARAMETERS ON ALUMINIUM FOAM FORMATION IN THE Al-6Si-3Mg ALLOY

Received – Prispjelo: 2013-06-21
Accepted – Prihvaćeno: 2013-10-15
Preliminary Note – Prethodno priopćenje

The aim of this research was to study the process parameters that promote foam formation by injecting N_2 into Al-6Si-3Mg wt % molten alloy with silicon carbide particles additions (SiC). An experimental design was proposed, in which the contents of SiC particles were 0, 10, 30 and 50 wt %, and the overheating was deﬁned as $\Delta T = T_F - T_L$, where T_L is the liquidus temperature and was determined by the cooling curve method and the foaming temperatures were selected as T_F at 630, 610, 580 and 570 °C. Flow and pressure of air blow were constant, 2,0 lt/min and 4,0 atm, respectively. The foam formation was possible only under two experimental conditions, 10 wt % SiC at $\Delta T > 12$ °C and 30 wt % SiC at $\Delta T > 10$ °C. The foams obtained under these conditions were stable, while with other conditions of experiments, bubble coallesence occurred. Finally, it was concluded that the foam formation occurred by SiC contents lower than 30 wt % SiC and temperatures slightly above the liquidus.

Keywords: Al-Si alloys, injecting N_2, Aluminium foam, solidiﬁcation

INTRODUCTION

The aluminium foams can be produced by several processes as gas injection (bubbling) and stirring a foaming agent (i.e. TiH_2) in a molten metal [1]. These materials are characterized for having a low density in combination with good mechanical properties, such as energy absorption [2, 3], permeability to fluids [4], and acoustic insulation [5, 6]. Hence their use has increased as a new engineering material [7, 8]. Their applications include impact resistant shields [9], filtres, heat exchangers [10], biomaterials [11], space parts [12] and porous electrodes [13].

Nowadays, there are several methods of aluminium foam production reported in the literature, Banhart J. [14, 15]. The production method defines the type of foam obtained, its density, cell size and morphology, and microstructure [16].

The metallic foams are materials formed by cells, in which their skeleton is the solid metal filled with bubbles of air or gas, and can be up to five times stronger than the wood, and have a weight of a tenth of their respective solid [17,18]. The production of aluminium based alloys foams by gas injection involves different process variables like mixing timechemical composition, temperature and viscosity of the molten metal, speed of the stirrer, flow of the gas, concentration and particle size of the ceramic [19]. The purpose of this work was to explore the feasibility and the most favourable processing conditions for the production of aluminium foams by N_2 injection.

R. Benavides-Treviño, A.Juarez-Hernandez, M. Hernandez-Rodriguez, Facultad de Ingeniería Mecánica y Eléctrica, UANL; O. Barceinas-Sanchez, CICATA-IPN; R.Almaguer, Depto. de Ingeniería Cyber Mayoreo S.A. de C.V. Mexico

EXPERIMENTAL PROCEDURE

Alloy preparation

The Al-6Si-3Mg alloy was prepared by melting Al 99,8 wt %, Al – 12 wt %Si, and Mg 98,0 wt % ingots in a silicon carbide crucible in an open electric furnace. Mixtures of this alloy with 10, 30 and 50 %wt SiC powder were prepared. The SiC was previously sieved separating -25 μm particles. The mixtures were prepared by keeping the alloy at 750 °C for 30 minutes, then adding the SiC whilst stirring at 1 200 rpm with an stainless steel double propeller previously coated and assembled in opposite direction, Figure 1, to achieve an efficient incorporation of the carbide particles.

During this stage the molten alloy showed an increase in its viscosity, which could be physically observed by the increase in the electric current consumed by the electric motor that drove the propeller. The optimum mixing time was determined as 20 minutes where all SiC was incorporated.

Foaming Process

Once the SiC particles were distributed homogeneously in the alloy and the temperature was stabilized, N_2 gas was injected into the liquid mixture by means of a tube of 0.5 mm of internal diameter for 10 minutes.The pressure was 3.0 atm and the flow 2.0 lt/min; these conditions allowed the formation of the foam. The main

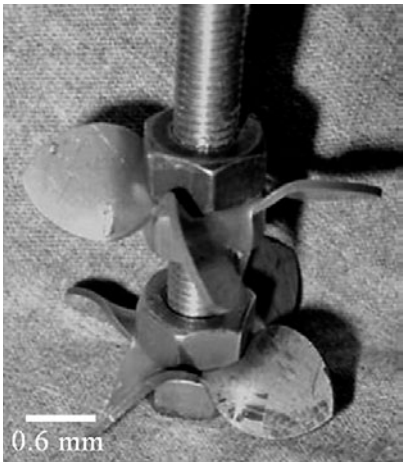

Figure 1 Opposite facing propellers

forces during foam formation are gravity, viscosity and capillarity, so it has been suggested that the SiC content and the temperature of the mixture are the main parameters to be studied [20]. Samples were micro and macro analyzed.

RESULTS AND DISCUSSION

Cooling Curves

Cooling curves were acquired under different SiC contents to determine the transition temperatures for four composites. These transition points were used to determine which temperature promotes a more stable foam and retarded the cell coalesence. Figure 2 shows the cooling curves for the Al-6Si-3Mg with 0, 10, 30 and 50 % wt SiC additions. It is seen that the liquidus temperature T_L remains almost constant, and the eutectic T_{Eu} temperature increases as the SiC content increases, T_L = 600+/- 2 °C and T_{Eu}= 557,1, 564, 564,2 and 567,9, respectively, which agrees with Gonzalez C. et al. [21] who studied the Al-Si system. In order to study the effect of viscocity, experiments were performed in different semisolid regions at the different amounts of SiC. Taking the liquidus temperature as a reference,

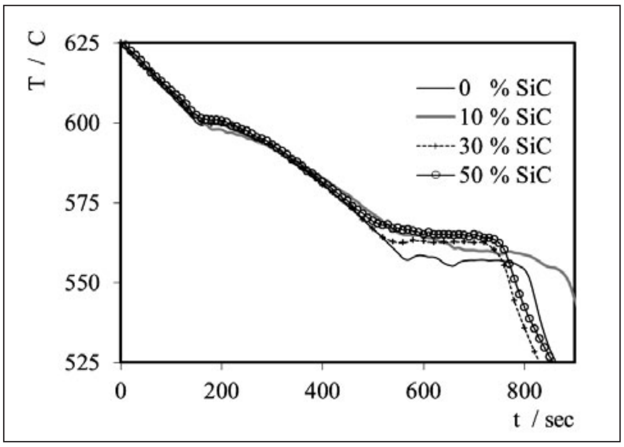

Figure 2 Cooling curves for Al-6Si-3Mg for 0, 10, 30 and 50 wt % SiC alloys.

foaming experiments were carried out fixing foaming temperatures as T_F at 630, 610, 580 and 570°C at which the gas N_2 was injected with a flow of 2 lt/min. The overheating was defined as $\Delta T = T_F - T_L$.

The Al-6Si-3Mg 10, 30 and 50 %wt SiC composites showed that the viscocity increased. Therefore, it was proposed to work in the mushy region $\Delta T < 0$ (liquid + α-Al). Under these conditions the bubble walls break apart. However, the process parameters which promote bubble stabilization and less collapsing were determined.

Aluminium Foam Production

Once the alloys solidified and cooled down to room temperature their micro and macro structures were analyzed. SiC particles were added to stabilize the bubles, retard or avoid coalescence, and increase the aluminium viscocity, which also depends on temperature. However, with 50 % wt SiC the bubbles were not stable and collapsed; this occurred at the four imposed temperatures. Figure 3 shows a comparison of the foams macrostructure produced under the following conditions: 10 wt % SiC and $\Delta T > 12$ °C; and 30 wt % SiC and $\Delta T > 10$ °C. Only these two conditions promoted the formation of foam, but the former resulted in more bubble stability. The next step consisted in removing the formed foam in order to achieve a faster cooling rate and allow a bigger foam volume, which in turn helped to establish a continuos production of foam. These experiments were done with 10 wt % SiC and $\Delta T = 12$ °C. Figure 3c shows a bigger foam volume with no bubble coalescence, which is attributed to the fact that this batch did not solidify in the crucible; also the cell size is more uniform.

From Figure 3, it can be also observed that in the region below the cells there is solid aluminum and large voids, which are evidence of bubble collapse; this region is located about 3 cm from the bottom. The bubble collapse can be attributed to the weight of the upper bubles and the higher temperature (closer to the molten aluminum). The upper part of the samples show the foam formation, also revealing an intermediate region where some evidence bubble collapse can be observed, whilst in the upper part the bubbles remained stable. It is important to note that the stability of the bubbles depends on the solidification time; at longer times the bubbles tend to collapse. On the other hand, shorter times proved to be more suitable to obtain larger volumes of foam.

The bubble collapse for the Al-6Si-3Mg alloy was attributed to two main factors: (a) high content of SiC (50 wt %), which hinders enough thinning of the bubble wall resulting in bubble breaking, and (b) at $\Delta T < 0$, (i.e. within the mushy region) the precipitation of α-Al produces bubble collapse due to wall breaking, Figure 4. As it was expected microstructure, Figure 5, consisted of SiC particles segregated to the interdendritic and intergranular regions of primary αAl dendrites, Al-Si and Al-$MgSi_2$ eutectics.

(a) (b) (c)

Figure 3 Aluminium foams obtained under the experimental conditions: (a) 10 %SiC and ΔT = 12 °C , (b) 30 %SiC and ΔT =10 °C, and (c) as (a) but extracting the foam from the crucible

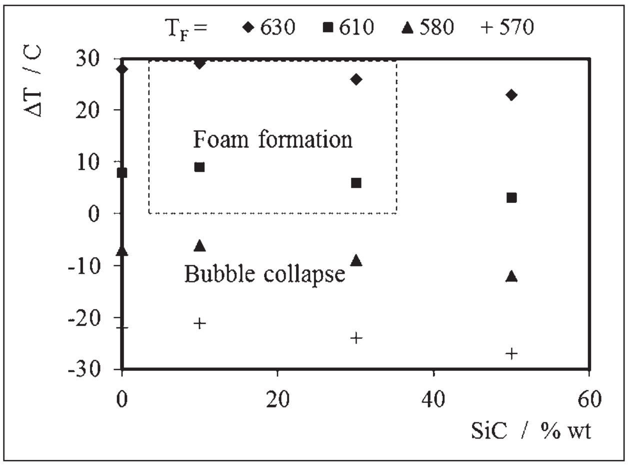

Figure 4 Proccess parameters diagram ΔT *vs* SiC wt % for Al-6Si-3Mg alloy foam formation

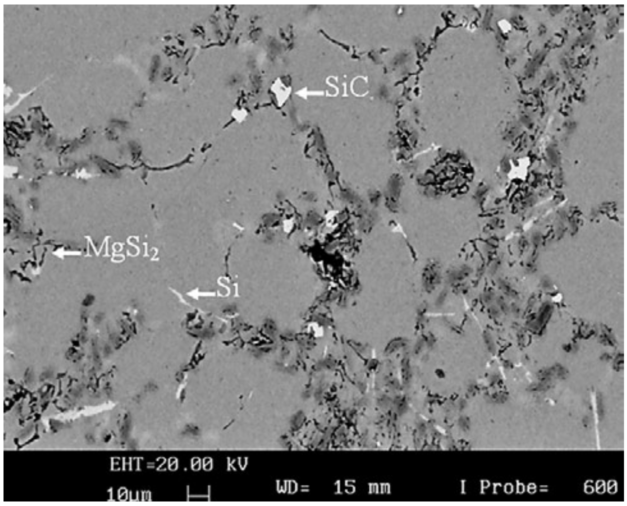

Figure 5 Microestructure of Al –6Si-3 Mg 10 SiC wt % foam

CONCLUSIONS

The production of aluminium foams requires a good control of the parameters which af fect the stability of the formed bubbles.

The most favourable conditions to achieve stability of the bubbles were: temperature close or above the liquidus temperature of the alloy, and SiC content between 10 and 30 wt %.

Although temperatures below the liquidus and the use of SiC content of 50 wt % increases the viscosity of the alloy, the stability of the bubbles decreases.

The production of aluminium foams by N_2 injection, achieved in this work, is an evidence that this method is technically feasible; however, a more sophisticated system is required to make the production in a continuous way.

Acknowlagements

The financial support given by Cyber Mayoreo S.A. de C. V. –CONACYT, Mexico, to undertake this research is greatly acknowledged [Grant N° 184422].

REFERENCES

[1] Ashby M.F, Evans A, Fleck N., Gibson L. J., Huitchinson J. W. and Wadley H. N. G., 2000, in “Metal Foam: A Design Guide”, Ed. Butterworth Heinemann.

[2] Zhang X. and Cheng G. Int. J. of Impact Enginnering 34 (2007) 1739-1752.

[3] Zhang C. and Saigal A. J. of Materials Processing and Technology 191 (2007) 256-259.

[4] Banhart J. Advance Engineering Materials 2 (2000) 188-191.

[5] Hai-jun Y. Trans. Nonferrous Met. Soc of China 17(2007) 93-98.

[6] Kadar C. et al. Mat. Sci. Eng. A462 (2007) 316-319.

[7] Baumeister J., Banhart J. and Weber M. Materials and Design 18 (1997) 4-6, 217-22.

[8] Hernandez-Rodriguez M. A. L. et al. Wear, 259 (2005) 958-963.

[9] Ramachandra S., Sudheer Kumar P., Ramamurty U. Scripta Materialia 49 (2003) 741-745.

[10] Laurencelle F. and Goyette J. Int. J. of Hydrogen Ener gy 32 (2007) 2957-2964.

[11] F. Gagliardi, et al., Mater Sci. Eng.A (2007), doi:10.1016/j.msea.2007.07.045

[12] Schwingel D. et al. Acta Astronautica 61 (2007) 326-330.

[13] Matsumoto Y., Brothers A. H., Stock S. R. and Dunand D. C. Mat. Sci. Eng. A447 (2007) 150-157.

[14] Banhart J. Journal of Materials 52 (2000) 22-27.

[15] Korner C. and Singer R. F . Advanced Engineering Materials 2 (2000) 159-165.

[16] Ma L., Song Z. and He D. Scripta Materialia 41 (1999) 785-789.

[17] Davies G.J y Zhen S. J Mater. Sci. 18 (1983) 1899.

[18] Banhart J. Foam Metal: Europhysics News 30 (1999) 17

[19] McMurry S. in ”Foams Physics” in Trinity College Dublin (1998) Britain.

[20] Goldfarb I., Kahn K. B. and Schreiber I., Izv Akand Nauk SSSR 2 (1987) 103.

[21] González-Rivera G., Campillo B., Castro M. Herrera M., Juárez-Islas. Mater. Sci. Eng. A279 (2000) 149-159.

Note: The responsibile for English language is the lector from Facultad de Ingeniería Mecánica y Eléctrica, UANL, Mexico