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Aluminium-SiC composite: Study of its mechanical properties

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Abstract

Cylindrical specimens with geometries and sizes, in agreement with the standard of American Society for Testing Materials (ASTM), they were used to characterize the tension behaviour of the composite. A significant effect of the SiC shape/size on the tensile behaviour of aluminium-based composite was observed, caused by the differences between the superheat (993 K) and the mould temperatures (333 K, 473 K, 623 K) in the melting practice. Ultimate tensile stress and Fracture Toughness factor for the composite showed a numerical advantage over the corresponding ones to the aluminium at a solidification speed of 82.5 $K \cdot s^{-1}$. At the mould temperature of 473 K, ultimate tensile stress decreased 8.9 % meanwhile Fracture Toughness factor increased 4.3 %. For mould temperatures higher than 473 K the size and number of SiC-clusters determined the tension behaviour of the specimens. High hardness values are obtained with high cooling rates (82.5 $K \cdot s^{-1}$) and it diminishes gradually as the cooling speed decreases for both sizes of particles.

1. Introduction

The development and optimization of the aluminium and its alloys is object of study for infinity of applications given its low cost of manufacture and density. These characteristics place to these materials in a position that is attractive for the design and construction of structural parts, aeronautics structures, automobile industry, lines of electric conduction, decorative figures, etc. As it is known, one in the ways to improve the characteristics of the aluminium and its alloys is by means of the insertion of fine particles into the metallic matrix [1-6]. These particles must be incoherent with the matrix and will be distributed in a homogeneous form through the entire specimen. Likewise, these particles will be sufficiently stable in the course of heat treatments.

In addition, the melting process and the size of the solid to obtain are aspects that should also be taken into account in order to attain the desired objective. In the present research, it is thought the solidification speed modifies the structure and therefore the mechanical characteristics of the metallic piece. Given the above-mentioned, it is expected the presented results contribute to the knowledge in the obtaining process of the composite in study.

The B.S. 1 B aluminium-based alloy (99.5% Al) has been selected to improve its hardness, tensile strength (UTS) and the Fracture Toughness (K_{Ic}), by means of the insertion of oxidized silicon carbide (SiC) particles into the metallic base [7]. In this work, fine particles of 6H (α-SiC) were aggregated to the melted alloy. Later on, a series of tests were carried out in the obtained solid. The aim of this research is to present the results attained as well as to discuss the relationship among obtained structure and the reached properties.

2. Materials and experimental procedures

Commercially pure aluminium (99.3% weight) was melted in a furnace with controlled atmosphere. Table 1 lists the composition of matrix material used in this study. Oxidized SiC particles (37 and 44 µm, maximum sizes; 19.5 and 24.4 average sizes) were introduced into the liquid aluminium in a proportion of 12% in weight. The mix was mechanically stirred then poured in a preheated mould; for mould, three temperatures were established: 333 K, 473 K; 623 K.

A standard 12.5 mm round tension test specimen was machined (Figure 1). Two types of specimen were used to study the effect of the SiC inclusions in tension, one of the types with circumferential vee notch (3 mm, notch length; 0.11 mm, radius of curvature of the crack-tip) [8]. Two groups of samples were prepared to do the measurements; each group with a maximum of 30 measuring cylinders.

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Table 1. As-supplied composition of aluminium matrix.

Metal (wt. %)								
Al	Cu	Fe	Mg	Mn	Si	Ti	V	Zn
99.308	0.001	0.342	0.001	0.114	0.081	0.008	0.01	0.123

Vickers hardness distribution in the cross-section of the specimen was measured under a load of 100 g for 15 s; the indentations were carried out close to the particles and in zones free of particles.

Figure 1. Picture of test specimen. In detail, the fracture surface can be viewed.

3. Results and discussion

3.1 Hardness

Hardness measures were taken in equidistant aligned points, initiating close to inclusions until areas free of particles. The hardness measures were averaged and graphically logged (Figure 2). A significant increase in the hardness was attained when the mould temperature is 333 K for both sizes of particle. The major value 76 HV is obtained with SiC particles with a maximum size of 37 um. The reached hardness value can be attributed to residual stresses resulting to solidifying, due to the marked difference between the coefficients of thermal expansion of the matrix and of the SiC particle (23.6 $\mu m \cdot m^{-1}K^{-1}$ for Al 99.5% wt.; 3.7 $\mu m \cdot m^{-1}K^{-1}$ for SiC) [9]. The light reduction in hardness for higher mould temperatures of the composites reflects a partial reduction of the residual stresses given that the time that is required to solidify is longer. To complete the analysis of the Figure 2, it is observed also a hardening of the utilized aluminium; said hardening can be caused by the formation of second phases given that the solidification time is increased. Although this aluminium is denominated "pure commercially", this aluminium contains impurities (see Table 1), which could react to form second phases that would modify the mechanical behaviour of the grains.

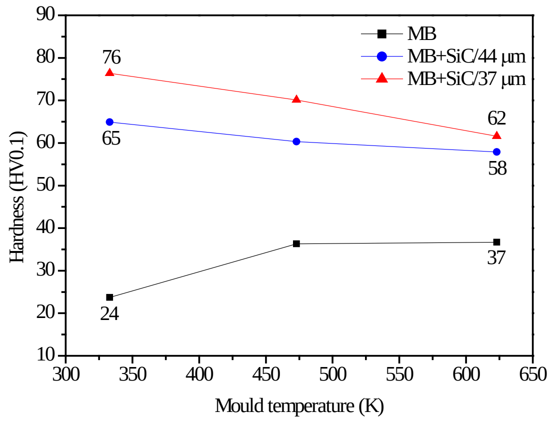

Figure 2. Hardness values in the cross-section of the cylindrical specimens that are obtained to three mould temperatures.

3.2 Tensile strength

Figure 3 shows the results of the tension test. A substantial increase in the UTS of the composite was observed. For particles with a maximum size of 37 μm the maximal strength is 139 MPa, meanwhile for particles of 44 μm the attained value is 124 MPa in samples poured in the preheated mould to 333 K. Assuming that the SiC particles are stable to temperature of the molten aluminium with superheat (993 K), it is clear that these particles would act as nucleating agents [10]; however, the temperature gradient between the melt and mould walls it causes that the solidification begins starting from the walls of the mould with presence of convection. In general, the structure at the end of the solidification process is formed by: dendrites; fractions of dendrites; disperse SiC-particles; SiC-clusters (see Figures 4). It was observed that the number of clusters and its size depend of the mould temperature (a vigorous convection prevent the SiC-clusters formation, see Figure 5) and the size of the amassed particles. It is clear that the formation of the SiC-clusters implies a reduction of the number of disperse SiC-particles; therefore, the final mechanical behaviour will depend primordially of the presence of such clusters. It is important to do mention that with a solidification speed of 82.5 $K \cdot s^{-1}$ no formation of SiC-clusters was observed. Therefore, at the mould temperature of 473 K the number of clusters and its size increase and the mechanical strength of the solid reduce. This last situation is clearly viewed in the Figure 3 for mould temperatures of 473 and 623 K when SiC particles with a maximum size of 37 µm are utilized. For particles of 44 µm the behaviour in tension is similar to the one described for the smallest particles, but for mould temperatures more high than 473 K the strength in tension is increased; this change in the behaviour indicates that the SiC-cluster size and its number work in favour of the studied property.

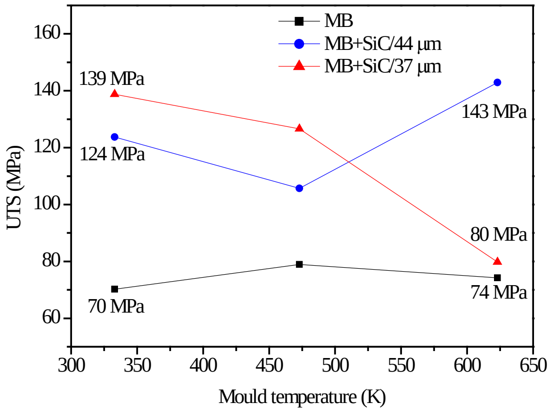

Figure 3. Tensile stresses of the cylindrical specimens that were obtained to three mould temperatures.

3.3 K_{Ic} Fracture Toughness

The cylindrical notched test (CNT) K_{Ic} Fracture Toughness Specimen showed improvements of this factor when SiC particles are added into the liquid (see Figure 6). The composites with a maximum size of particle of 37 y 44 µm that were obtained in the mould preheated at 333 K, they showed fracture toughness values of 3.1 and 4.4 MPa(m)^{½}, respectively. These values are greater than the corresponding to the sample free of carbides (1.7 MPa(m)^{½}. In this particular case, the SiC particles with a maximum size of 44 µm showed the best result. With regard to the above-mentioned, when the SiC-clusters is formed, the effect of to disperse the crack propagation is more effective with SiC-clusters of greater size; in addition, it is important to make to notice that the effect increases yet with longer times of solidification. Finally, in the case of the composite with smaller silicon carbide particles (37 um), the reached size of the SiC-clusters for higher mould temperatures than 473 K affects in negative way the fracture toughness factor.

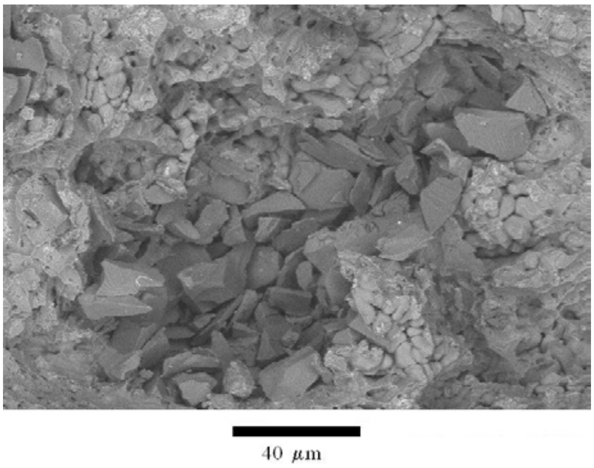

Figure 4. Image of the fracture surface corresponding to the specimen that was obtained to the mould temperature of 473 K. In the image a cluster of SiC particles can be viewed and around the cluster the signs of a ductile fracture can be noted.

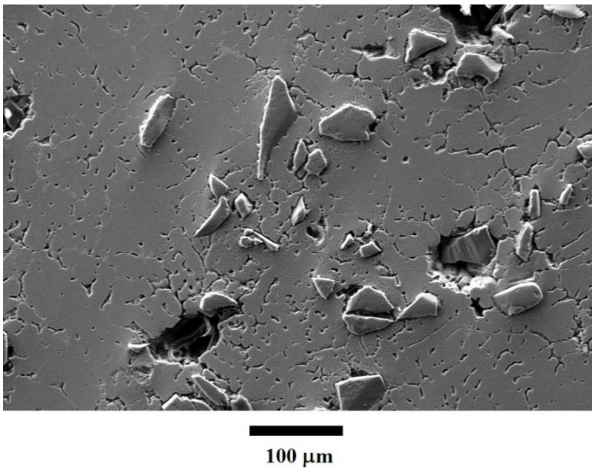

Figure 5. Cross-section micrograph of the composite containing SiC particles (44 µm, maximum size). The observed structure corresponds to specimen solidified to 82.5 K/s.

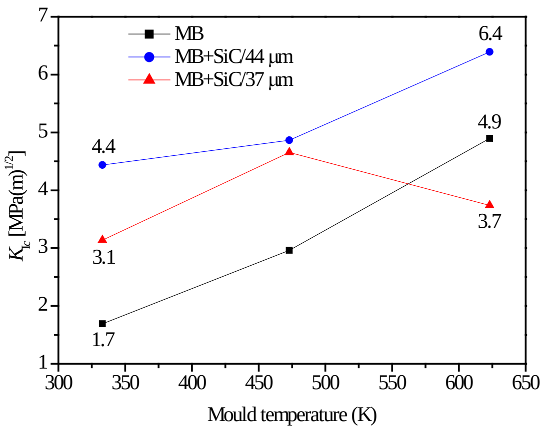

Figure 6. Dependence of the Fracture Toughness from the mould temperature in the employed cylindrical specimens.

4. Conclusions

4.1 The present research clearly shows that the hardness and tensile properties of the pure commercially aluminium is improved with the addition of oxidized silicon carbide particles.
4.2 To the mould temperatures of 473 and 623 K, the presence of SiC-clusters is observed indistinctly of the sizes of the particles utilized.
4.3 A notorious drop in the hardness and UTS is observed with increasing the mould temperature from 333 to 623 K in the melting practice, except for the composite with SiC particles of 44 µm that it shows a significant increase in the UTS for higher mould temperatures than 473 K.
4.4 The Fracture Toughness factor (K_{Ic}) is visibly increased in the studied composites, and still improves for higher mould temperatures than 333 K, except for the composite with SiC particles of 37 µm for the which to higher mould temperatures than 473 K it exhibits a decline of this factor.
4.5 The result indicates that the size and number of SiC-clusters modifies the tendency of the UTS and K_{Ic} at higher mould temperatures than 473 K.

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