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DISPERSION OF GRAPHITE NANOPARTICLES IN A 6063 ALUMINUM ALLOY BY MECHANICAL MILLING AND HOT EXTRUSION

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Abstract. Composites of Al-6063 aluminum alloy powder reinforced with graphite particles were prepared by mechanical milling, sintering and subsequent hot extrusion. Mechanical properties and microstructural characterization were done as a function of graphite content. For lower graphite contents mechanical resistance is increasing as the graphite content is increased as well; for higher contents, graphite agglomeration reduces mechanical resistance. This variation is related to the graphite dispersion / agglomeration into aluminum alloy matrix.

1. INTRODUCTION

Considerably scientific research has been carried out in recent years to develop stronger, stiffer and wear-resistant engineering materials than the available commercial materials presently. Metal matrix composites (MMC) are regarded as excellent materials to obtain superior properties to those of the constituent phases and also to satisfy the above requirements [1]. However, the use of some MMC is limited by the high cost of their processing.

Aluminum-based metal matrix composites (MMC) reinforced with ceramic particles are demanded because of their low density and high specific stiffness. In addition, ceramic particles increase significantly wear resistance, high temperature strength and refractoriness. Different processing techniques can be used to the production of MMC. They can be grouped into two main routes depending on the state of the matrix during manufacturing process. These are the liquid and the solid routes.

Dispersion strengthened materials (DSM) belong to the group of composite materials, which are made mainly by the techniques of powder metallurgy (PM), which is considered as a solid route. The microstructure of DSM is composed by a polycrystalline matrix, in which dispersed particles are incorporated (mainly oxide, carbide and/or nitride).

Aluminum–based composites reinforced with ceramic particles are promising engineering materials with adequate strength to meet industrial requirements. By mechanical milling (MM), it has been possible to disperse graphite nanoparticles into a pure aluminum matrix [2,3], producing favorable effects on mechanical properties.

Most of the work done so far on aluminum alloy composites has been based on the 2XXX series of Al-Cu alloys. The 6XXX series of Al-Mg-Si alloys are widely used as medium strength structural alloys made by extrusion, which have the advantages of good weldability, corrosion resistance, and immunity to stress corrosion cracking. A typical

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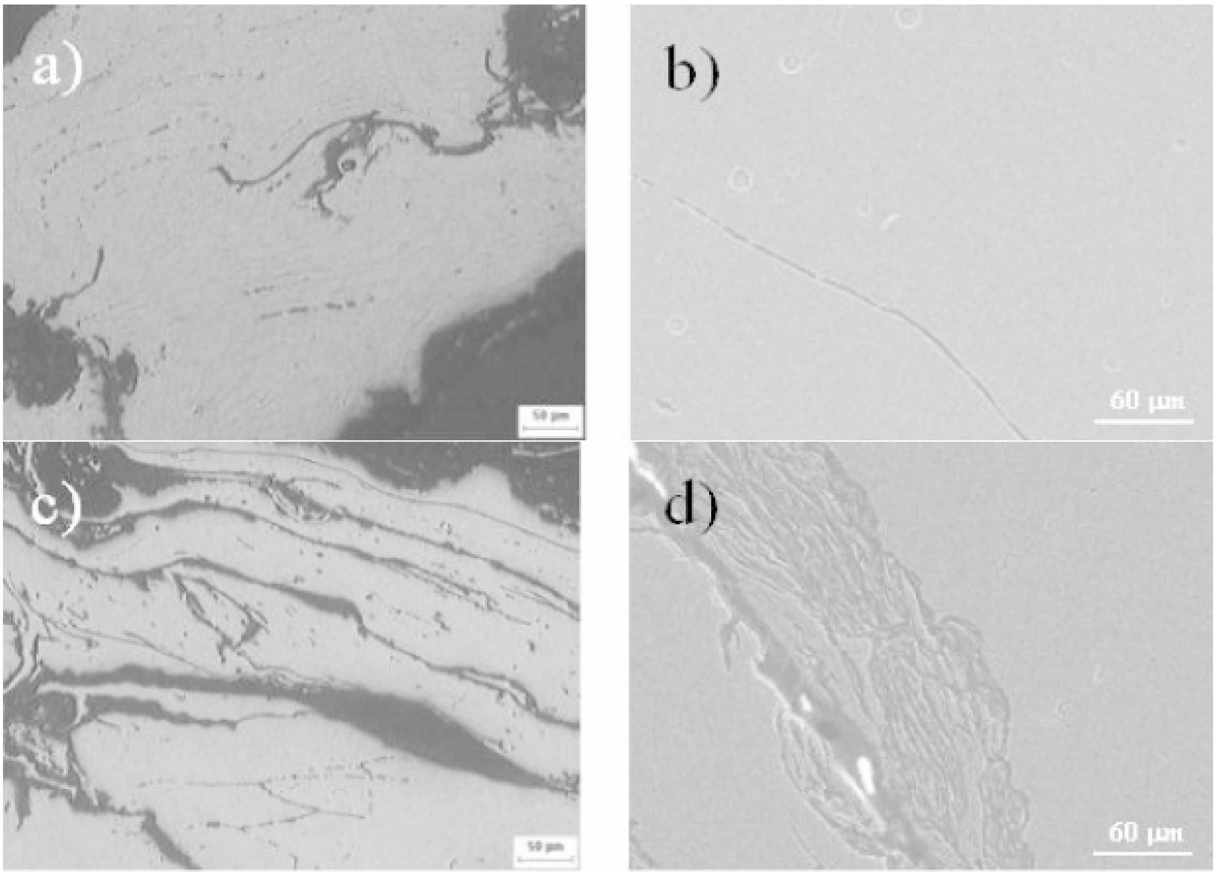

Fig. 1. Microstructure observed in as-milled powders; (a)-b) 0.5 wt.% C, and (c)-(d) 2.0 wt.% C.

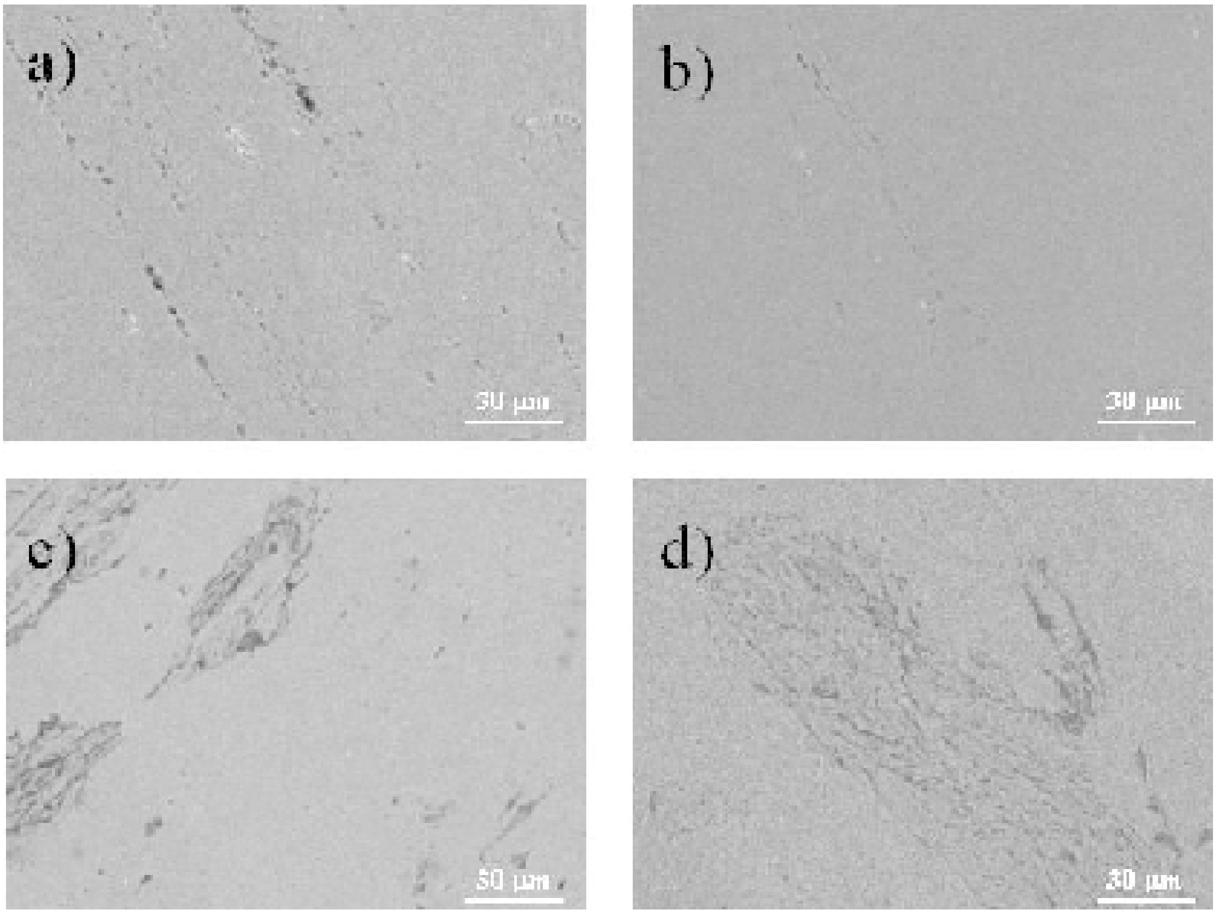

Fig. 2. Microstructure in extruded samples, (a)-(b) 0.5 wt.% C, and (c)-(d) 2.0 wt.% C.

6XXX type of aluminum alloy that could be used as a matrix for the composites is the 6063 alloy.

This work deals with the microstructural and mechanical characterization of an aluminum alloy 6063 reinforced with graphite dispersion by MM.

2. EXPERIMENTAL PROCEDURE

The raw powder materials used were Aluminum alloy 6063 (-200 mesh in size) hereafter named as Al_{6063} and previously milled graphite powder. Graphite powders were milled for 4 and 8 h, hereafter named as C4 and C8 respectively. As expected C8 presents lower particle size than C4. Samples with different graphite content were prepared and studied, 0.25, 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, and 2.0 wt.% C. Each mixture was mechanically milled in a high energy Simoloyer mill for 2 h. The milling ball to powder weight ratio was 20 to 1. Consolidated products were obtained by pressing for 2 minutes at ~ 468 MPa in uniaxial load. Pressed samples were pressure-less sintered at 823K for 1 h at under vacuum (<1 Torr). Sintered products were hot extruded at 823K. Extrusion ratio was 16. Reference samples were processed under the same experimental conditions eliminating the milling step (samples identified as MIX in results section). Microstructural characterization was performed by using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Mechanical characterization was performed by tensile test, compression test and microhardness. Results from SEM and tensile test are presented and discussed.

3. RESULTS

In order to investigate the microstructure homogeneity after milling of Al_{6063} with graphite powder, the as-milled powders were analyzed by SEM. Fig. 1 shows representative images from milled powder mixture from Al_{6063} and C8. Samples with lower graphite content have its better dispersion (Fig. 1a).

It is noted that a lamellar structure of the two constituent phases in as-milled samples is more evident for samples with higher graphite contents. In extruded samples, it was notice that graphite agglomeration is present in materials with more than 0.75 wt.% C. This agglomeration had a negative effect on mechanical properties as shown forward.

The microstructures of the extruded bars from powders milled for 2 h are shown in Figs. 2a-2d. Homogeneous dispersion is seen in the microstructure of samples extruded from powders milled with

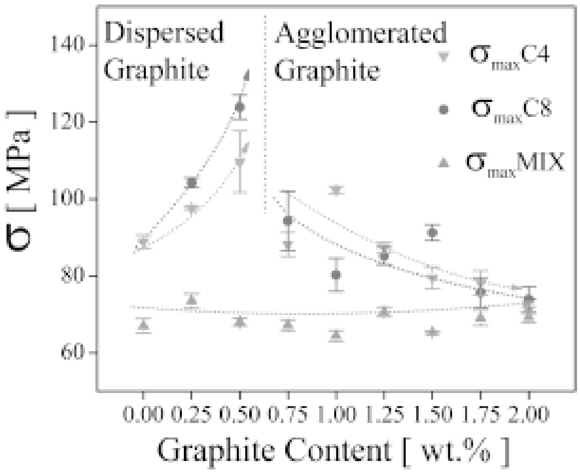

Fig. 3. Yield Strength in Al_{6063}-C composites. Notice the two regions as a function of graphite content.

graphite contents lower than 0.75 wt.%. On the other hand, non-homogeneous dispersion and agglomerates of graphite particles between the Al_{6063} matrix powder boundaries are clearly seen in the case of sample with high graphite content.

4. MECHANICAL PROPERTIES

Fig. 3 shows the tensile strengths of the Al_{6063}-graphite composite bars as a function of graphite content. Testing was carried out only in the longitudinal direction since samples were not length enough for testing in the transverse direction. Graphite content and its particle size have a modest effect on mechanical properties. Usually, is expected that the addition of graphite to metal matrix composites (MMC´s) decreases their tensile and/or compression strengths [1]. The main reason is the significantly lower strength of graphite compared with the matrix alloy. However, in this work, the materials with graphite contents between 0.0 and 0.75 wt.% showed that as the graphite content increases, the mechanical resistance increases too. Additionally, at these compositions, graphite C8 (with lower particle size) has better effect than C4. This behavior can be attributed to a better dispersion of graphite particles of their lower contents (see Figs. 2a and 2b). On the other hand, by increasing graphite contents above 0.75 wt.%, the mechanical resistance decreases. Obviously this behavior is related to the agglomeration shown by these samples independently of the size of graphite particles.

It is noted that the worst properties were found in as-mixed samples (MIX Fig. 3) and in samples with higher graphite contents (Fig. 3). This poor mechanical resistance is associated with the inhomogeneous distribution of graphite and the lamellar structure (Fig. 2). It has been reported before that longer milling time improves graphite dispersion [1,3]. We suppose that by using longer milling time the mechanical properties can be enhanced by refining the microstructure and improving graphite dispersion.

5. CONCLUSIONS

Graphite content and particle size have a modest effect on mechanical properties. As the graphite content increases, the mechanical resistance increases too, until 0.75 wt.% of graphite content. At higher contents, a graphite agglomeration is presented, and this effect reduces the mechanical resistance. This variation is related to the graphite dispersion / agglomeration into aluminum alloy matrix.

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