

## **Processing and Manufacturing of Metal Matrix Aluminum Alloys Composites Reinforced by Silicon Carbide and Alumina Through Powder Metallurgy Techniques**

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**Abstract.** Composites are combinations of two materials in which one of the materials, called the reinforcing phase, is in the form of fibers, sheets, or particles and is embedded in the other materials called the matrix phase. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. In this work of research aluminium alloy AA6061 was reinforced by 5, 10 and 15% (in mass %) of SiC and Al<sub>2</sub>O<sub>3</sub> by mechanical alloying in a vibratory type SPEX mill, cold uniaxial compaction and vacuum sintering in order to investigate the influence of the particulate phase in the microstructure and mechanical properties of the composites obtained. The microstructure of the powders and the sintered materials were evaluated by SEM and the hardness was evaluated by hardness tests.

## 1. INTRODUCTION

In fact, mechanical alloying process using ball-milling and/or rod-milling techniques, has received much attention as a powerful tool for fabrication of several advanced materials, including equilibrium, non-equilibrium (e.g., amorphous, quasicrystals, nanocrystalline) and composite materials. In addition, it has been employed for reducing some metallic oxides by milling the oxide powders with metallic reducing agents at room temperature. The MA is an unique process in that a solid state reaction takes place between the fresh powder surfaces of the reactant materials at room temperature. Consequently, it can be used to produce alloys and compounds which are difficult or impossible to be obtained by the conventional melting and casting techniques [1,2]. The main aim of this work is to report the effect of the high energy milling processes on the fabrication of aluminium matrix composite powders, reinforced with a homogeneous dispersion of silicon carbide and alumina reinforcing particles.

## 2. EXPERIMENTAL PROCEDURE

Aluminum alloy AA6061 was distinctly reinforced by silicon carbide (SiC) and alumina (Al<sub>2</sub>O<sub>3</sub>) in mass fractions of 5, 10 and 15% producing two composites. The technique of high-energy milling in a SPEX vibratory mill type was applied in order to post process the alloy AA6061 with their reinforcements. Soon after the high-energy milling step follows cold uniaxial compaction and sintering under vacuum (- 650 mmHg) fabricating records of the respective composites with 26.10 mm diameter, 6 mm in height and mass of 8g,

then the metallographic preparation aims to prepare samples for microstructural analysis by scanning electron microscopy (SEM) and Vickers microhardness testing according to NBR NM 188-1 with a load of 5 Kgf.

### 3. RESULTS AND DISCUSSION

#### 3.1. Effect of high-energy milling on particle diameter of the composite AA6061 + SiC and AA6061 + Al<sub>2</sub>O<sub>3</sub>

According to Figure 3.1 the reinforcement of silicon carbide was more efficient in the milling process compared to the strengthening of alumina, providing a further reduction in particle diameter with increasing grinding time from 30 to 60 minutes and also with increasing fraction of reinforcement [3,4,9]. Indication D (0.5) represents the particle diameter at which 50% by volume of particles are below their respective values.

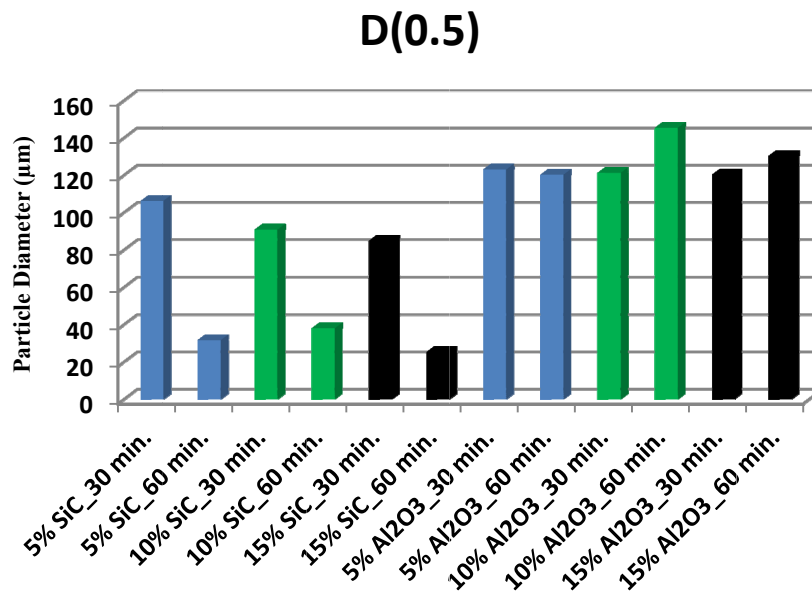


Figure 3.1 - The particle diameter of the composite reinforcement with 5, 10 and 15% bulk silicon carbide and alumina subjected to 30 and 60 minutes of grinding, respectively.

#### 3.2. Distribution of reinforcing phase (SiC and Al<sub>2</sub>O<sub>3</sub>) after compaction and sintering of composites

The composite reinforced with silicon carbide presents a more deformed microstructure in comparison with the composite reinforced with alumina as shown in figure 3.2, this behavior results from the high-energy milling process, since the silicon carbide grinding speeds increasing strain rate at which the particles are subjected to AA6061 matrix during the process [5,6].

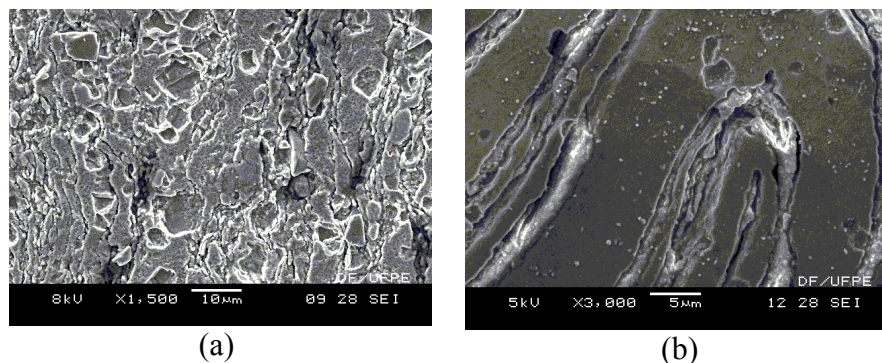


Figure 3.2 - Distribution of the strengthening phase in the composite reinforced with 10% (a) of silicon carbide subjected to high energy ball milling for 60 minutes (a) after compaction and sintering. (b) 10% bulk alumina ( $\text{Al}_2\text{O}_3$ ) subjected to high energy ball milling for 60 minutes (a, b) after compaction and sintering.

### 3.3. Testing Vickers hardness (HV) in the composites reinforced with silicon carbide (SiC) and alumina ( $\text{Al}_2\text{O}_3$ )

Both composite Vickers hardness results showed higher than in the unreinforced matrix after compaction and sintering as shown in figure 3.3. The fact that the composite reinforced with silicon carbide have better hardness of the composite reinforced with alumina notes the efficiency of silicon carbide in both the milling process, where it worked effectively in reducing the particle diameter, as well as to promote a further hardening of the composite end contributing to the achievement of higher results of Vickers hardness. The timid performance enhancing alumina accelerate the reduction of particle diameter in the high-energy milling is reflected also in the low efficiency of AA6061 matrix to strengthen and promote the hardening of the composite after the final stages of compaction and sintering. Figure 3.2 shows very different microstructures of both composites. The microstructure of the composite reinforced with silicon carbide appears more deformed than the microstructure of the composite reinforced with alumina confirming the efficiency of silicon carbide in

high-energy milling contributing to the reduction of particle diameter and the final composite and promoting hardening of AA6061 matrix and increasing the values of Vickers hardness as compared to unreinforced AA6061 matrix and also on the hardness of the composite reinforced with alumina. [5,6,7,8,9].

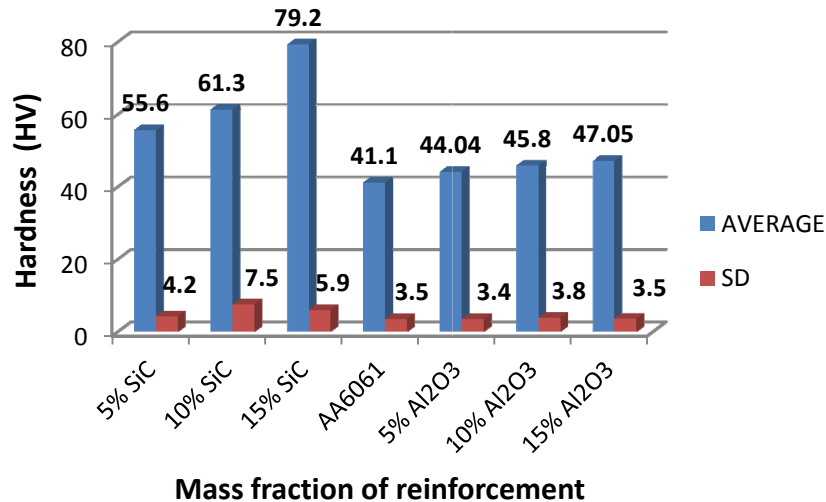


Figure 3.3 - Mean and standard deviation (SD) of results for ten hardness indentations in composites reinforced with silicon carbide (SiC) and alumina (Al<sub>2</sub>O<sub>3</sub>).

#### 4. CONCLUSIONS

- ✓ During the high-energy milling the silicon carbide acted more effectively in reducing the particle diameter compared to the reinforcement of alumina.
- ✓ The microstructure of the composite reinforced with silicon carbide appears more deformed compared with the microstructure of the composite reinforced with alumina as a result of silicon carbide promoting high rate deformation of particles in the AA6061 matrix in the stage of high-energy milling.
- ✓ The silicon carbide was also more superior in relation to the strengthening of alumina promoting higher values of Vickers hardness in the composite.
- ✓ The powder metallurgy route was used successfully, since both composites showed superior results of Vickers hardness in comparison with the unreinforced matrix.

## 5. REFERENCES

- [1] Davis RM, Mcdermott B, Koch CC. Mechanical alloying of brittle materials. *Metall Trans A* 1988;19A:2867.
- [2] Arik H. Production and characterization of in situ  $Al_4C_3$  reinforced aluminum-based composite produced by the mechanical alloying technique. *Mater Des* 2004;25:31.
- [3] S. Kamrani, R. Riedel, S. M. Seyed Reihani, H.J. Kleebe, in: Effect of reinforcement volume fraction on the mechanical properties of Al SiC nanocomposites produced by mechanical alloying and consolidation. *Journal of Composite Materials*, 313: 44, 2010.
- [4] M. A. P. Santos, C. A. Costa, in: Moagem de pós de carboneto de silício em moinho planetário. *Cerâmica* 51: 392-397, 2005.
- [5] K. R. Ahmad, W. J. Lee, R. M. Zaki, M. N. Mazlee, M. W. M. Fitri, S. S. Rizam, J. B. Shumsul, in: The microstructure and properties of aluminium composite reinforced with 65  $\mu m$  alumina particles via powder metallurgy. *ICoSM*, 2007.
- [6] C. Dhadsanadhep, T. Luangvaranunt, J. Umeda and K. Kondoh, in: Fabrication of Al/ $Al_2O_3$  Composite by Powder Metallurgy Method from Aluminum and Rice Husk Ash. *Journal of Metals, Materials and Minerals*. Vol.18 No.2 pp.99-102, 2008.
- [7] M. Adamiak, in: Selected properties of the aluminium alloy base composites reinforced with intermetallic particles. *Journal of Achievements in Materials and Manufacturing Engineering* Vol. 14 (2006) 1-2.
- [8] M. Tabandeh Khorshid, S. A. Jenabali Jahromi, M. M. Moshksar, in: Mechanical properties of tri-modal Al matrix composites reinforced by nano- and submicron-sized  $Al_2O_3$  particulates developed by wet attrition milling and hot extrusion. *Materials and Design* 31 (2010) 3880-3884.
- [9] K. Zilnyk, O. M. Cintho, in: Influência da moagem de alta energia na porosidade de produtos da metalurgia do pó. 4º Encontro de Engenharia e Tecnologia dos Campos Gerais (2008).

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