*Materials Science Forum Vols. 727-728 (2012) pp 259-262*
*Online available since 2012/Aug/24 at www.scientific.net*

*doi:10.4028/www.scientific.net/MSF.727-728.259*

# Preparation of Metal Matrix Aluminum Alloys Composites Reinforced by Silicon Nitride and Aluminum Nitride Through Powder Metallurgy Techniques

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**Keywords:** Powder Metallurgy, AA6061 Aluminum Alloy Metal Matrix Composites, Mechanical Alloying, Vacuum Sintering

**Abstract.** The aliminium alloys are of particular interest to both the aerospace industry and automotive industry because of their attractive combinations of properties such as medium strength, formability, weldability, corrosion resistance and low cost. Compared with a metal matrix material, significant improvements in the mechanical and physical properties such as strength, toughness, and thermal conductivity can be achievied in metal matrix composites (MMCs). In this work of investigation aluminium alloy AA6061 was reinforced by 5, 10 and 15% (in mass %) of $Si_3N_4$ (silicon nitride) and AlN (aluminium nitride) by mechanical alloying in a vibratory type SPEX mill, cold uniaxial compaction and vacuum sitering 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 means of SEM and the hardness and were evaluated by hardness test.

## INTRODUCTION

The mechanical alloying (MA) process, using ball-milling techniques, has received much attention as a powerful tool for the fabrication of several advanced materials including equilibrium, nonequilibrium (e.g., amorphous, quasicrystals, nanocrystalline, etc.), and composite materials. The MA is a unique process in which 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 that are difficult or impossible to obtain by the conventional melting and casting techniques [1-6]. 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 nitride and aluminium nitride reinforcing particles.

## EXPERIMENTAL PROCEDURE

Aluminum alloy AA6061 was distinctly reinforced by silicon nitride ($Si_3N_4$) and aluminum nitride (AlN) 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. 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.

## RESULTS AND DISCUSSION

### Effect of high-energy milling on particle diameter of the composite AA6061 + AlN and AA6061 + $Si_3N_4$

According to figure 3.1 both composites decreased the particle diameter with increasing grinding time from 30 to 60 minutes, validating the efficiency of both reinforcements in order to break and accelerate the mechanisms of the high energy milling process. [3,5,7,8]. Indication D (0.5) represents the particle diameter at which 50% by volume of particles are below their respective values.

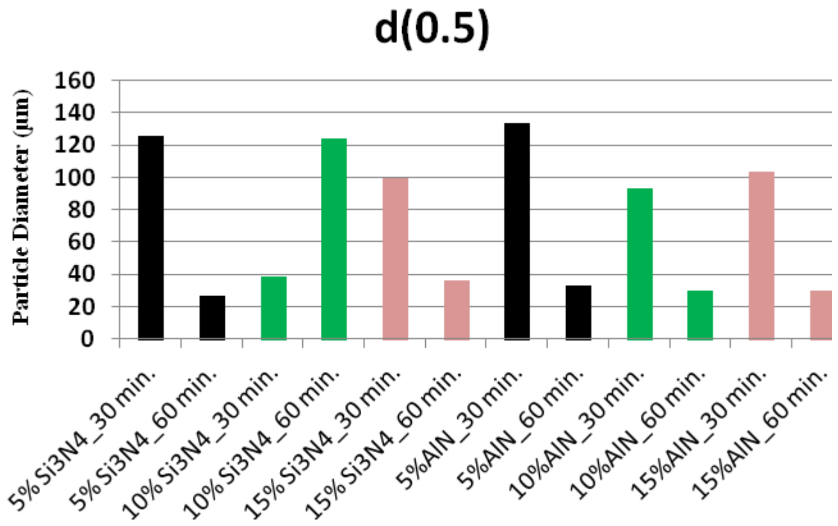
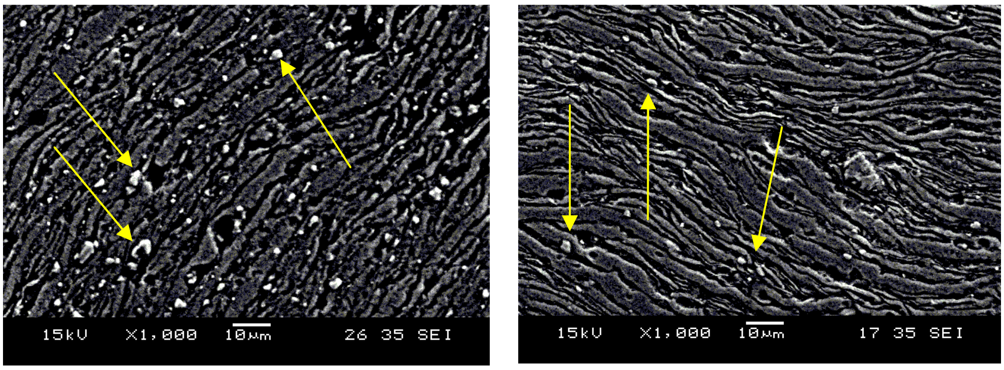



Figure 3.1 - The particle diameter of the composite reinforcement with 5, 10 and 15% bulk silicon nitride and aluminium nitride subjected to 30 and 60 minutes of grinding, respectively.

### Distribution of reinforcing phase (AlN and $Si_3N_4$) after compaction and sintering of composites

Figures 3.3 (a) and 3.3 (b) show micrographs of scanning electron microscopy (SEM) of both composites, the reinforcement phase ($Si_3N_4$ and AlN) can be clearly identified as indicated by the arrows in yellow in both composites. In figure 3.3 (a) the composite reinforced with aluminum nitride has a microstructure without the presence of porosity with uniform distribution of reinforcing phase and no settlements for the three mass fractions of 5, 10 and 15% used [9].




(a) (b)

Figure 3.3 - Distribution of the strengthening phase in the composite reinforced with 10% (a) of aluminum nitride (AlN) subjected to high energy ball milling for 60 minutes (a) after compaction and sintering. (b) 10% bulk silicon nitride ($Si_3N_4$) subjected to high energy ball milling for 60 minutes (a, b) after compaction and sintering.

The composite reinforced with silicon nitride in figure 3.3 (b), also presents a microstructure without porosity with uniform distribution of the reinforcing phase ($Si_3N_4$) and without the presence of agglomerations.

**Testing Vickers hardness (HV) in the composites reinforced with aluminum nitride (AlN) and silicon nitride ($Si_3N_4$)**

According to Figure 3.5 both composites showed superior results of Vickers hardness in comparison with the unreinforced matrix AA6061 after compaction and sintering. The best results of hardness for the composite reinforced with silicon nitride is related to a greater tendency of silicon nitride to fragment during the milling process. With a higher rate of fragmentation the reinforcement is distributed more evenly in the matrix providing greater efficiency in the hardening of AA6061 matrix [3,5,8,9].

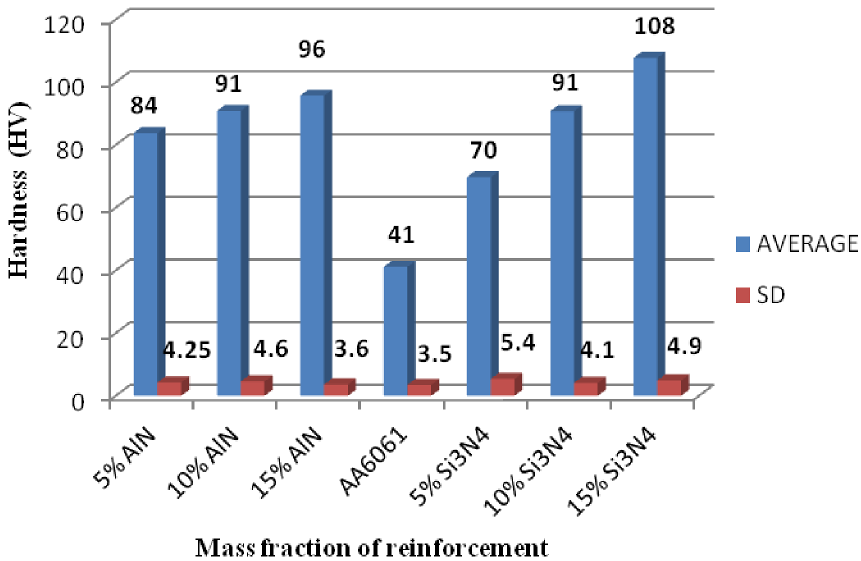



Figure 3.5 - Mean and standard deviation (SD) of results for ten of hardness indentations in composites reinforced with aluminum nitride (AlN) and silicon carbide ($Si_3N_4$).

## CONCLUSIONS

- ✓ Strengthening of silicon nitride was more efficient in relation to the strengthening of aluminum nitride in order to accelerate the process of high-energy milling and act more significantly in reducing the particle diameter;
- ✓ The process of high-energy milling was highly effective in reducing the particle diameter and uniform distribution of reinforcing phase as seen in micrographs of scanning electron microscopy (SEM) of both composites after compaction and sintering;
- ✓ The techniques of high-energy milling, uniaxial cold compaction and vacuum sintering were used successfully, since, in both the mechanical property of the composite (Vickers hardness) was increased compared to AA6061 matrix compacted and sintered without reinforcement;
- ✓ The uniform distribution of reinforcing phase provided by high energy ball milling can also be confirmed by the low standard deviation values obtained in the ten indentations, since there is no uniformity in the distribution of enhancing the standard deviation increase;
- ✓ Reinforcement of silicon nitride was also more effective on increasing aluminum nitride composite providing the greatest results of Vickers hardness.

## ACKNOWLEDGEMENT

The authors would like to thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE) and UFPE.

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