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Comparison of Al-matrix composites produced by different techniques

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The work analyses aspects of the production of Al based composites with particulate reinforcement, via solid, semi-solid and liquid matrix. Composites were produced by mixing A6061 and AlN powders either by conventional mixing of matrix and reinforcement powders or high energy mechanical alloying, followed by cold pressing and hot extrusion; by addition of SiC in Al-Si and Al-Si-Mg alloys in the rheocast semi-solid state; and by controlling NbAl₃ phase precipitation in liquid Al (*in situ* formation of the reinforcement).

1. INTRODUCTION

Many different techniques have been developed to produce composites, using matrix in vapour, liquid, solid or semi-solid state. When processing at high temperatures (vapour deposition), interface reactions can result in poor quality. When processing via liquid matrix, differences in specific weights of the components can result in highly heterogeneous distribution of reinforcing particles, and anisotropic properties [1]. Besides, the distinct nature of the components can result in poor interface interaction or excessive reaction between the components. When producing *in situ* composites these problems can be overcome [2].

The compocasting process employs semi-solid rheocast matrix with thixotropic properties which helps the entrapment of ceramic particles and prevents their sedimentation [3].

Powder metallurgy techniques bring advantages over processing from liquid state, once the lower involved temperatures reduce surface reactions. These techniques also promote good dispersion of reinforcing particles. A new approach on powder techniques is the utilisation of high energy milling which can lead to finer dispersion of particles and more effective interaction between matrix and reinforcement [4].

This work compares results of different processing techniques to produce Al matrix composites.

2. EXPERIMENTAL PROCEDURES

Production of composites from solid matrix - A6061 + 5%vol and 15%vol AlN were produced from A6061 powder, with average particles size $33\mu\text{m}$ and AlN powder with average particles size $8\mu\text{m}$. Conventional low-energy mixing and mechanical alloying were used. After milling samples were extruded (extrusion ratio of 25/1 at 500°C), producing 5mm diameter bars with 98% of the theoretical density.

Production of composites from semi-solid matrix - A356 + 5%vol and 15%vol SiC (plate-like morphology, 6 and $30\mu\text{m}$ average size) were produced from matrix in the semi-solid state. Comopocasting conditions used: continuous stirring from 650 to 600°C , stirring speed 1000rpm.

Production of composites from liquid matrix – *in situ* reinforcements - Al/NbAl₃ composites containing 6 and 18vol% NbAl₃ were produced by Nb dissolution in liquid Al at 950°C , for 4h.

3. RESULTS AND DISCUSSIONS

3.1. A6061/AlN produced by powder technology

Figure 1 shows typical microstructures of A6061/AlN composites produced by mixing the elemental powders in conventional or high energy mills. It also shows the powders after mixture. Powders produced by conventional mixture presents discrete particles of AlN and A6061; on the other hand, the mixture produced in the high energy mill the original AlN particles suffered fragmentation and were entrapped by the A6061 particles. While the conventional mixing process only produces mixed powders and does not change their original characteristics, the mechanical alloying produces a composite powder. The matrix properties are enhanced by the severe cold work and aluminium oxide and carbide dispersion imposed by the high-energy milling. The reinforcing particles are reduced in their size, and the population of cracks, always present in ceramic particle surface, is practically eliminated.

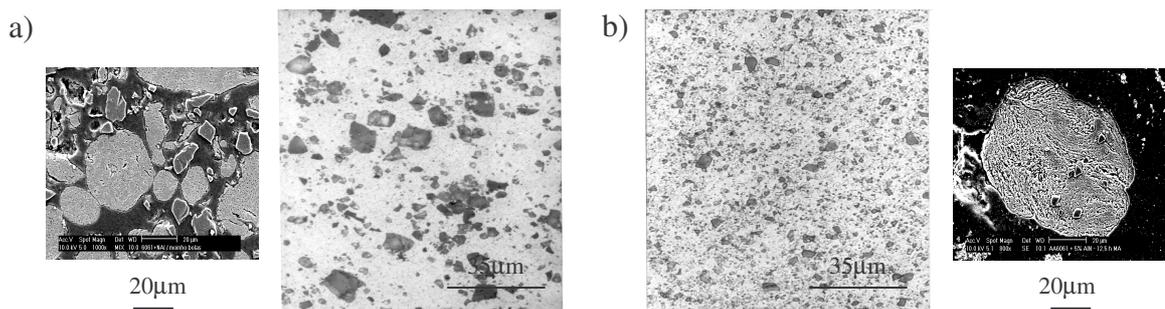


Figure 1. a) Mixture of A6061 +AlN powders and respective A6061 + 15% AlN composite produced by conventional milling; b) same, using high energy milling (10h).

These differences will provide, in the consolidated composite material, a better, finer reinforcement distribution in composites produced with mechanical alloyed powder, with consequences in their mechanical properties, as shown in Table 1.

Table 1

Mechanical properties of A6061/AlN composites produced by different powder routes.

Material →	A6061 + 5% AlN		A6061 + 15% AlN	
Process ↓	σ_{\max} (MPa)	HV	σ_{\max} (MPa)	HV
Conventional mixture	206±2	63±2	173±10	66±2
High energy milling	404±12	126±6	361±17	145±7

3.2 A356/SiC produced by compocasting

Figure 2 shows composite produced by addition of 15%SiC particles to A356 rheocast slurry and Table 2 shows typical properties of some composites produced by compocasting.

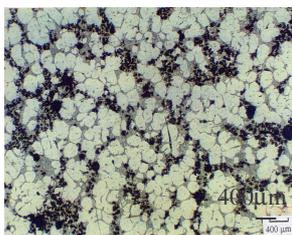


Fig. 2. Microstructure A356/15%SiC produced by compocasting

Table 2

Mechanical properties of composites A356/SiC produced by compocasting

Material	σ_{\max} (MPa)	ϵ (%)
A356 rheocast	136 ± 5	3.4 ± 1.6
A356 + 5%SiC (6μm)	125 ± 15	2.5 ± 1.7
A356 + 15%SiC (6μm)	88 ± 12	2.1 ± 1.8
A356 + 15%SiC (30μm)	153 ± 13	1.7 ± 0.02

During processing, the presence of SiC particles increases the material viscosity, reducing convection and favouring coarsening and agglomeration of solid phase in the slurry, which can jeopardise the liquid distribution among solid globules and, as consequence, the distribution of reinforcing particles in the composite. Size of particles plays an important role: fine particles present higher tendency to agglomerate, resulting in big particles which can not fit the interglobular liquid regions. Best results are obtained when a compromise between particles size and volume of liquid regions is achieved.

It can be observed that in general the produced composites present worse mechanical properties than the alloy in the rheocast state, due to agglomeration of SiC.

3.3 Al/NbAl₃ produced by *in situ* formation of the reinforcing particle

Figure 3 shows microstructure of Al-NbAl₃ composite produced by adding Nb to liquid Al, and a isolated NbAl₃particle. The composite presents an acceptable dispersion of the reinforcing phase, due to the rapid cooling during solidification, which can prevent sedimentation. NbAl₃ particles are discrete, presenting a characteristic polygonal morphology, with sizes ranging from 2 to 20μm. The intermetallic NbAl₃ is formed directly from metallic Nb immersed in liquid Al at high temperature (950°C) by a dissolution process. Al atoms penetrate in the Nb surface, forming a reaction layer with NbAl₃ composition. This product is attached to the Nb particle for some time forming a continuous, compact layer. Cracks appear in this layer in crystals boundaries; as the specific volume of NbAl₃ is higher than the specific volume of the Nb itself, liquid Al penetrates in the cracks, detaching NbAl₃ crystals to the surrounding liquid. Stirring must be provided to prevent high concentration of NbAl₃ particles close to the dissolving Nb plate and to assure a good dispersion of the reinforcing in the matrix.

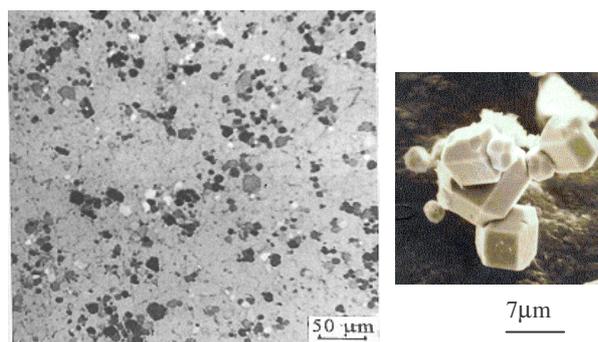


Figure 3. Microstructures of Al + 18%NbAl₃ and isolated NbAl₃ particle.

Table 3 shows typical results of mechanical properties of Al/NbAl₃ composites produced by *in situ* formation of the reinforcement. Significant increase in tensile strength due to the presence of reinforcing particles of NbAl₃, even at high temperature is obtained. Elongation suffers drastic reduction with the presence of the hard NbAl₃ particles in the matrix.

Table 3

Mechanical properties of Al/NbAl₃ produced by *in situ* formation of NbAl₃ in the liquid Al.

Material	σ_{\max} (MPa)	ϵ (%)	σ_{\max} 150°C (MPa)	ϵ (%) 150°C
Al	65 ± 1	48	41 ± 1	35
Al+ 6% NbAl ₃	88 ± 1	35	73 ± 1	19
Al+ 12% NbAl ₃	98 ± 3	21	76 ± 2	8

4. CONCLUSIONS

Reliable composites can be produced by simply mixing the powders followed by extrusion, without the need of sintering. High energy milling produces composite powders and therefore finer dispersion of the reinforcing particles in the matrix and composites with higher mechanical properties. In the compocasting process, proper relation between liquid fraction in the slurry and size of ceramic particles must be achieved to produce acceptable composites. *In situ* formation of the reinforcing phase in the liquid matrix by controlling solidification rate produces composites with perfect interaction between constituents, besides a good dispersion of reinforcing particles. Fine reinforcing particles can be produced by appropriate control of kinetics of their formation and providing conditions to prevent particles agglomeration.

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