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Selected properties of the aluminium alloy base composites reinforced with intermetallic particles

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Properties

ABSTRACT

Purpose: The main aim of this work is to investigate two types of intermetallics TiAl and Ti_3Al as reinforcement and their influence on selected properties and microstructure of aluminium matrix composites.
Design/methodology/approach: Aluminium matrix composites were produced employing the atomised aluminium alloy AA6061 as metal matrix, when as reinforcement TiAl and Ti_3Al intermetallics particles were used. The powders were cold pressed and then hot extruded. To evaluate the effect of mechanical milling two types of ball mills were used: a low energy (horizontal ball mill) and a high energy one (eccentric ball mill). Reinforcement contents for both processes 5, 10, 15 % by weight. To determine hardness Vickers tests were performed. Microstructure observations were made by optical microscopy and scanning electron microscopy SEM.
Findings: Based on the examinations carried out one can state that the mechanical milling can produce composites powders with homogenous distribution of reinforcement particles. The mechanically milled and extruded composites show finer and better distribution of reinforcement particles what leads to better mechanical properties of obtained products.
Research limitations/implications: In order to evaluate with more detail the possibility of applying these composite materials at practical application, further investigations should be concentrated on the interface reaction of the matrix and reinforcing particles during elevated temperature exposition and their influence on mechanical properties.
Practical implications: The composites materials produced by this way have shown significant improvement of the mechanical properties in comparision with matrix materials. Good properties of the composites make them suitable for various technical and industrial applications.
Originality/value: It should be stressed that the materials as intermetallic compounds with outstanding mechanical properties and good thermal stability were developed making them a powerful material to be used in this kind of composites as the alternative for the reinforcements usually investigated and utilized to the composites materials production - alumina or silicon carbide.
Keywords: Composites materials; Aluminium matrix composites AMCs; Intermetallics; TiAl; Ti_3Al

1. Introduction

The metal matrix composites, can exhibit unique properties if compared with traditional materials as well as potential for new applications. They were designed with the aim to conjugate the desired characteristics of two or more materials, constitute one of the most important research fields in materials science and engineering since the beginning of 60 decade. The applicability of these materials is based on the improvement of both mechanical properties at high temperatures and wear resistance, principally when compared with conventional alloys without reinforcement. The aluminum metal matrix composites, in particular the hardenable aluminum alloys matrix, such as AA2XXX, AA6XXX and AA7XXX groups, are used in applications where good mechanical characteristics and low specific weight are required. The applicability of these materials is based on the improvement of both mechanical properties at high temperatures and wear resistance, principally when compared with conventional alloys without reinforcement. The industry related to transportation was the first to use these materials, where many components made from them are used in automotive industry [1, 2].

Among all processes that have been developed to improve the characteristics of aluminum and its alloys, the mechanical alloying process has received more attention. John Benjamin and his co-workers [3] produced fine and uniform dispersions of oxide particles (Al_2O_3, Y_2O_3 and ThO_2) in nickel-base superalloys, which could not be made by conventional powder metallurgy methods, by means of high-energy ball milling of powders. The process of mechanical alloying consists in repeated welding-fracture-welding of a mixture of powder particles in a high-energy ball mill. The central event is that the powder particles are trapped between the colliding balls during milling undergoing deformation and/or fracture process. In mechanical alloying of at least one ductile component, there is an initial stage when deformation dominates the process, followed by a stage in which welding is the predominant. After a certain period of milling, the powder is hard enough and fracture dominates the process. At the end of the process, the powder reaches a steady state characterised by equilibrium between welding and fracture [4, 5].

Currently this process is being used to produce numerous materials and alloys, including supersaturated solid solutions, amorphous materials, intermetallic compounds and metal matrix composites. Powder metallurgy techniques combined with mechanical milling offers innumerable advantages over casting metallurgy, making possible not only to improve the existing properties but also conferring new properties. The temperatures involved during the material production by powder metallurgy are lower which promotes a less interaction between the materials, minimizing interfacial reactions and making possible to reach superior mechanical properties. The use of PM and MM to fabricate metal matrix composites allows also to better control of the volumetric fraction of the reinforcement in a relatively large range and their uniform distribution [6, 7].

The reinforcements usually investigated and utilized to the composites materials production are alumina or silicon carbide in the form of short/long fibers or particles, because of their hardness, thermal stability and relatively low weight. In the last years appeared new reinforcement candidates such as nitrates, borates, other oxides and carbonates. However, materials as intermetallic compounds with outstanding mechanical properties and good thermal stability were developed making them a powerful material to be used in this kind of composites [8, 9].

The titanium aluminides, Ti_3Al and TiAl, have been considered one of most important reinforcement candidates because they exhibit low density and excellent mechanical properties, principally at high temperatures. Their main use is centered in the aerospace industry, especially in turbine elements that are submitted to high temperatures, in substitution to nickel superalloys, and with an important economy in weight. The utilization of these reinforcements came from the possibility to make use low density materials and that permit to produce aluminum composites with good wear resistance [10, 11].

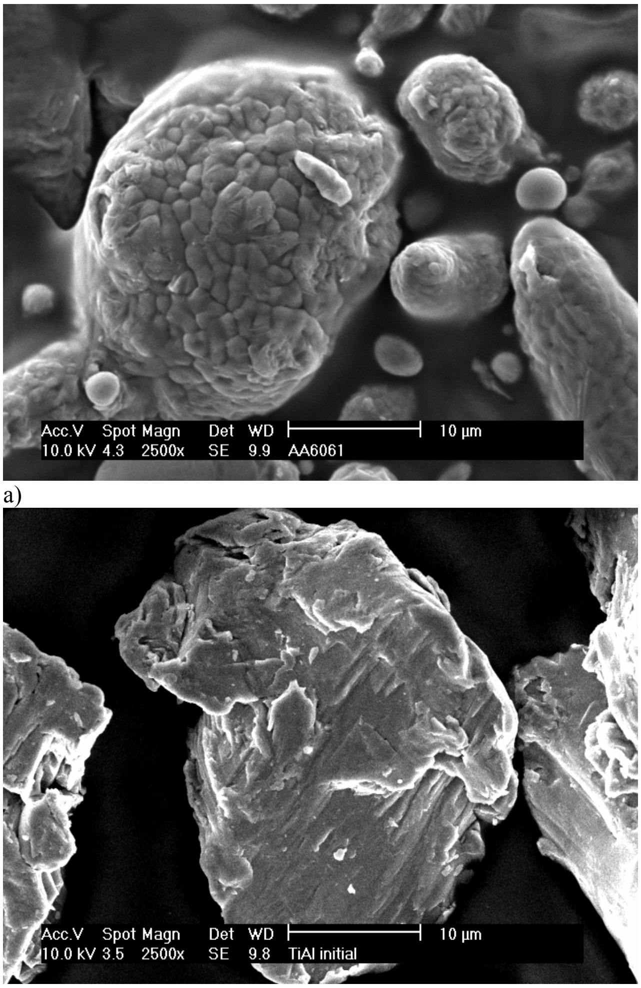
The main aim of this work is to investigate two types of intermetallics TiAl and Ti_3Al as reinforcement and their influence on selected properties and microstructure of aluminium matrix composites.

2. Experiment

Aluminium matrix composites were produced employing the atomised aluminium alloy AA6061 produced by the Aluminium Powder Co Ltd. (UK) as metal matrix, when as reinforcement TiAl and Ti_3Al intermetallics particles produced by SE-JONG Materials Ltd. (Korea) were used. The chemical composition of powders used are given at Table 1 and 2. Particles size were less than 75 µm for aluminium alloy powders and TiAl intermetalics and less than 50 µm for Ti_3Al titanium aluminide, Figure 1.

To evaluate the effect of mechanical milling two types of ball mills were used: a low energy (horizontal ball mill) and a high energy one (eccentric ball mill).

The low energy L.E mixing process consist of powders mixing at horizontal ball mill for 2 hours, ball diameter 10 mm, ball material quenched stainless steel AISI 420, ball to powder weight ratio 10:1, rotation speed 150 rpm, process control agent Microwax (1%)



a)

b)

Figure 1. Morphology of as received powder particles used in the experiments, a) AA6061 aluminium alloy, b) TiAl intermetallic

Table 1
Chemical composition of the atomised aluminium alloy powder

AA6061	Elements’ concentration, weight %						
	Fe	Si	Cu	Mg	Cr	Others	Al
	0.03	0.63	0.24	0.97	0.24	<0.3	Bal

Table 2
Chemical composition of the titanium aluminide powders

Particle type	Elements’ concentration, weight %						
	Ti	Al	V	Fe	N_2	O_2	H_2
Ti_3Al	Max. 83.36	Max. 15.35	0.55	0.025	0.06	Max. 0.59	Max. 0.15
TiAl	Max. 36.25	Max. 62.14	0.32	0.015	0.043	Max. 0.63	Max. 0.10

The composite powders were produced by high-energy ball milling. The planetary (eccentric) ball mill was used with the following parameters, weight ball to powder ratio 6:1, ball diameter 20 mm, ball material quenched stainless steel AISI 420, milling time 18 hours, process control agent Microwax (1% wt).

Reinforcement contents for both processes 5, 10, 15 % by weight. To characterize the obtained composite powders measurements of the apparent density according to MPIF Standard 28 , flow rate for 50 g of powder [10], as well as morphological and metallographic, examination was performed. Three sets of samples with 5, 10 and 15 % (wt.) for each of reinforcement type and blending process were prepared.

The powders were cold pressed in the 25 mm in diameter cylindrical matrix with 300 MPa pressure and then extruded at 500-510°C with graphite as lubricant without caning and degassing.

To avoid the excessive grain growth due to high level of stored energy, in case of samples after mechanical milling, annealing process were performed at 400 °C for 1 hour. Extruded bars of 5 mm diameter and near theoretical density were obtained. To determine the ultimate tensile strength (UTS) tensile tests were performed on samples with 50 mm measuring length.

To determine hardness Vickers tests were performed in the parallel plane related to the extrusion direction. Microstructure observations were made by optical microscopy and scanning electron microscopy SEM.

3. Results and discussion

In the contrary to conventional casting processes the PM route of composite materials production makes possible to obtain wide range of reinforcement particles percentage addition without typical for them segregation. Observation of morphology of powder mixture after low energy mixing process and after high energy mechanical milling process respectively allows to state that the low energy mixing process do not change morphology of the initial particles, allows for better distribution of reinforcement particles but can not completely liquidate their agglomerates.

Mechanical milling process has improved the reinforcement distributions throughout the whole particle Figure 2. However, after 10 hours of mechanical milling, the particles are predominantly laminar. In the microstructure, it can be observed that the intermetallic reinforcement, has undergone plastic deformation, as well as the ductile aluminium matrix. As pointed before, deformation predominates at the initial stage of high-energy milling, followed by a stage when welding predominates. After 10 hours of milling, the observed morphology indicates that the process is still at the early stages. Whenever the reinforcement

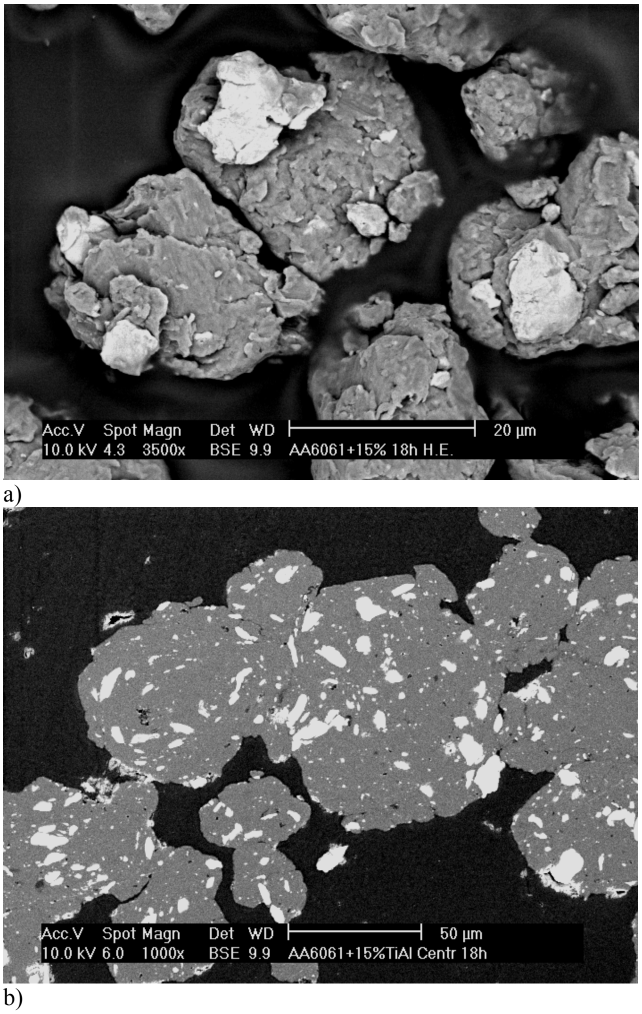
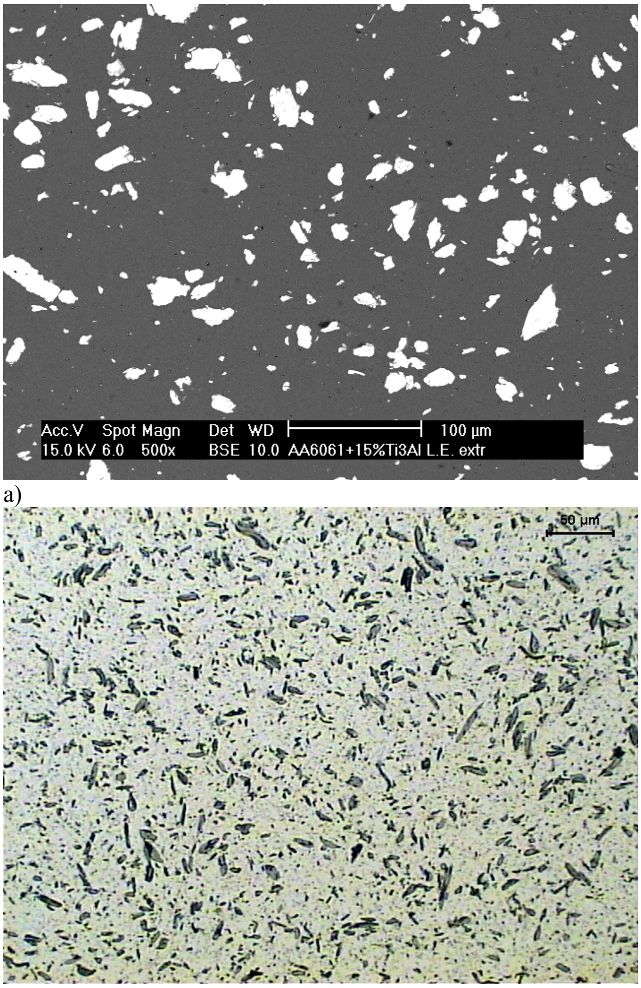


Figure 2. Morphology a) and microstructure of cross section b) of the composite AA6061+15% TiAl powder particles after 18h of mechanical milling, SEM

particles are situated between the aluminium particles during the ball collision, they are integrated in the resulting welded particle, forming a composite particle. With the work hardening due to the deformation and welding process that the particles undergo, fractures increase and reach the equilibrium with welding. At this moment, the equiaxial particles are formed. It can be seen that the longer milling time has improved the reinforcement distributions throughout the whole particle, and has produced equiaxial morphology. Intermetallic particles has undergone plastic deformation as well as the fragmentation what is not possible in case of low energy mixing processes. Another characteristic, which indicates that the process has reached its steady state, is the recuperation of apparent density [10].



a)

b)

Figure 3. Microstructure of cross section of composite AA6061+15% Ti_3Al powder particle a) after 2h of L.E. mixing and b) after 18h of H.E. mechanical milling

Flattened particles have worse packing in case of the non-free flowing powder, but the equiaxial as-received powder and also the mechanical-milled powder after the achievement of the steady state show better packing, providing a higher value of apparent density. It can be observed that the composite powders have flow ability. In the final products of composites materials, depending on the reinforcement size and shape, the density difference, type of matrix material, agglomeration can occur. Although the extrusion processes tends to minimize this problem reinforcement particles agglomeration is the most appointed cause of low performance of this class of materials.

To avoid this problem mechanical milling can be used to improve the distribution of the reinforcement particles through the matrix. The big difference between particle size and their distribution through the aluminium matrix can be observed. In the mechanically milled composites one can see very fine distribution of small reinforcement particles and absence of agglomerates; however, there is fraction of particles with elliptical or flattened shape Figure 3.

Mechanical milling through the high degree of deformation, high density of dislocation, oxide and reinforcement particle dispersion in the matrix increase the hardness when the finer microstructure increase the mechanical properties of composites materials.

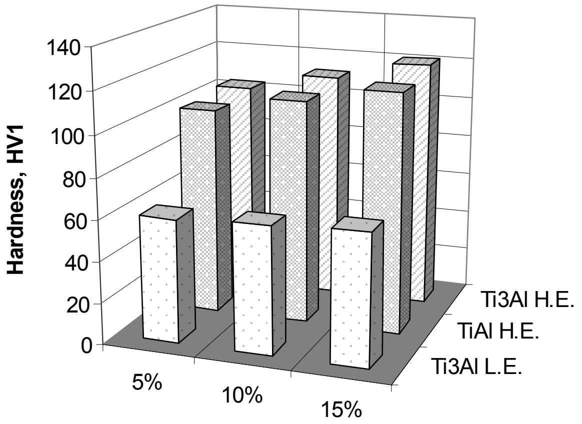


Figure 4. Hardness of the extruded composites

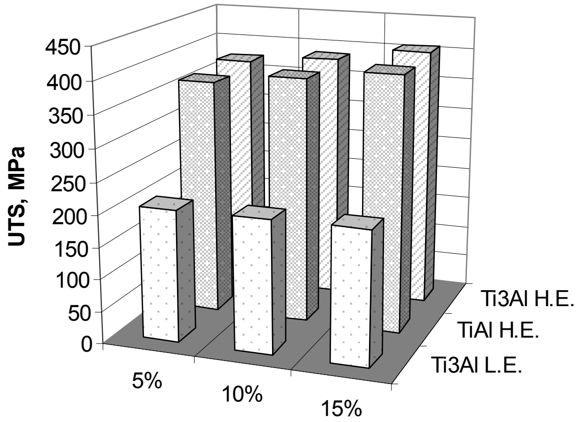


Figure 5. Ultimate tensile strength of the extruded composites

Figure 4 and 5 shows the hardness and ultimate tensile strength of extruded composites and aluminium AA 6061 alloy. One can see increase of the mechanical properties due to the mechanical milling process. Hardness and UTS for AA 6061 aluminium alloy extruded without reinforcement particles achieve about 50 HV1 and about 200 MPa respectively. L.E. refers to low energy mixing process, H. E. refers to high energy mechanical milling and for both of processes different concentration of reinforcement particles were used. As it can be see hardness of composite materials is only slightly higher after mixing process and small increase of hardness value is observed when reinforcement contents increase. In case of composites after mechanical milling hardness is more than twice of aluminium alloy. The same tendency can be observed for tensile properties however mixing process do not influence UTS value. Again mechanical milling change almost twice ultimate tensile strength of investigated composites. Moreover until 15 % of reinforcement particles contents UTS is growing indicating to good interfacial bonding of matrix and reinforcement particles.

4. Conclusions

Based on the examinations carried out one can state that the mechanical milling can produce composites powders with homogenous distribution of reinforcement particles. The mechanically milled and extruded composites show finer and better distribution of reinforcement particles what leads to better mechanical properties of obtained products, however directed structure oriented corresponding to the extrusion direction was developed during the extrusion process. Addition of the TiAl and Ti_3Al particles of the reinforcing materials to the aluminum matrix increased hardness of the composite materials obtained. The significant hardness increases in comparison with row aluminium alloy (more than twice) was observed in case of mechanically milled composites and only 20 -25 HV1 for low energy mixed and hot extruded composites. The addition of intermetallic reinforcement particles to the low energy mixed and extruded composites do not influence their tensile properties. In case of mechanically milled composites the finer microstructure and dispersion hardening increase mechanical properties of composites materials. The higher reinforcement content results in higher particles dispersion hardening. Composites reinforced with 15% of TiAl or Ti_3Al reach about 400 MPa UTS. There are no big difference between investigated intermetallics type and mechanical properties of composites obtained.

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