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Mechanical alloying for fabrication of aluminium matrix composite powders with Ti-Al intermetallics reinforcement

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Materials

ABSTRACT

Purpose: The aim of this work is to report the effect of the high energy milling processes, on fabrication of aluminium matrix composite powders, reinforced with a homogeneous dispersion of the intermetallic Ti_3Al reinforcing particles.
Design/methodology/approach: MA process are considered as a method for producing composite metal powders with a controlled fine microstructure. It occurs by the repeated fracturing and re-welding of powders particles mixture in a highly energetic ball mill.
Findings: Mechanical alloying, applied for composite powder fabrication, improves the distribution of the Ti_3Al intermetallic reinforcing particles throughout the aluminium matrix, simultaneously reducing their size. Observed microstructural changes influence on the mechanical properties of powder particles.
Research limitations/implications: Contributes to the knowledge on composite powders production via MA.
Practical implications: Gives the answer to evolution of the powder production stages, during mechanical alloying and theirs final properties.
Originality/value: Broadening of the production routes for homogeneous particles reinforced aluminium matrix composites.
Keywords: Mechanical alloying; Aluminium matrix composites; Intermetallics

1. 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. Basically the ball milling has evolved from being standard technique in milling of ores in mineral dressing and particle size reduction in powder metallurgy to important techniques for the preparation of materials with enhanced mechanical and physical properties either new phases or new engineering materials [1-4].

Mechanical alloying may be defined as a method for producing composite metal powders with a controlled fine microstructure. It occurs by the repeated fracturing and rewelding of powder particles mixture in a highly energetic ball mill. As originally carried out, the process requires at least one fairly ductile metal to act as a host or binder. Other components can consist of other ductile metals, brittle metals, and intermetallic compounds or nonmetals and refractory compounds. The high energy involved in the MA process fragments and cold re-welds powder particles, that form the initial mix. The powder particles are continuously trapped between colliding balls and balls/container what raises the level of microstructural strain, enhancing its mechanical properties. Besides high energy milling can bring many changes to powders subject to such a process, including refinement of particle size and crystallite size, formation of amorphous phases, deformed bonds at surfaces and changes in boundary energies. Because of these changes the free energy of reactants and the kinetics reaction can be substantially modified [5-10]

The main aim of this work is to report the effect of the high energy milling processes on fabrication of aluminium matrix composite powders, reinforced with a homogeneous dispersion of the intermetallic Ti-Al reinforcing particles.

2. Material and methods

As a matrix material air atomised powders of aluminium alloy - grade EN AW6061 from The Aluminium Powder Company Ltd. (UK) was used. The chemical composition of the alloy is given in Table 1. The particle size of the powder was < 75μm with the volume size distribution D50 = 29.6 μm. SEM morphology and microstructure of the initial (as received) powder particles used are given in Figure 1.

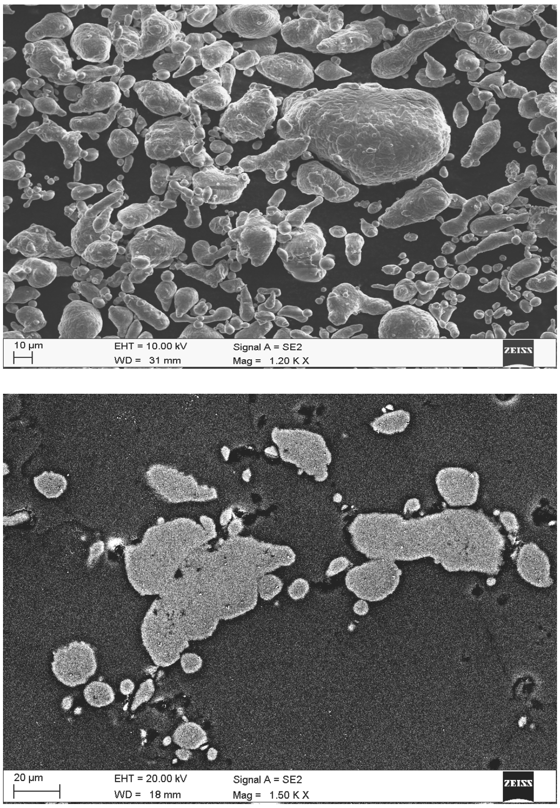

Fig. 1. Morphology and microstructure of as received powder particles of EN AW6061 alloy, SEM

Reinforcement particles used, were the Ti_3Al titanium aluminide (particles size less than 50 μm), produced in the hydride-dehydride process by SE-JONG Materials Ltd. (Korea). The chemical composition of the intermetallic compound is given in Table 2. The particle size of the powder was < 75μm with the volume size distribution D50 = 22.66 μm. SEM morphology and microstructure of the initial (as received) powder particles used are given in Figure 2.

Table 1.
Chemical composition of the matrix - air atomised aluminium alloy powder EN AW6061

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

Table 2.
Chemical composition of the reinforcement particles - titanium aluminide powder Ti_3Al

Elements' concentration, weight %						
Ti	Al	V	Fe	N_2	O_2	H_2
83.36	15.35	0.55	0.025	0.06	0.59	0.15

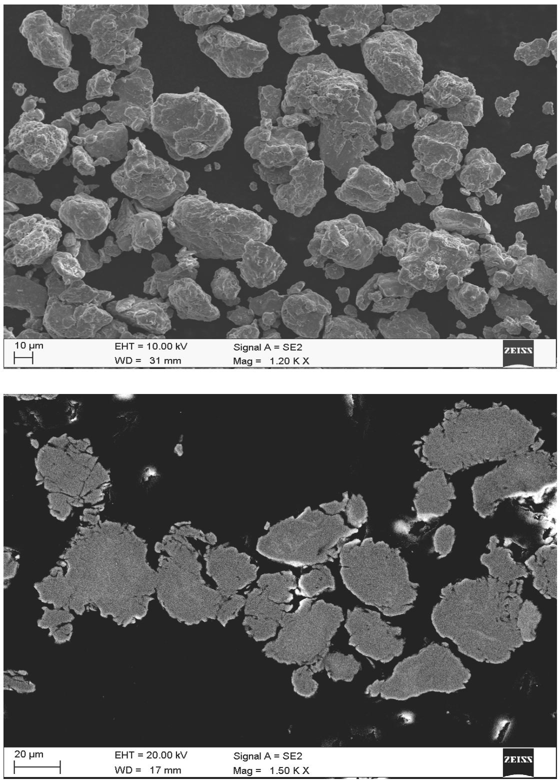

Fig. 2. Morphology and microstructure of as received powder particles of Ti_3Al intermetallic compound, SEM

Composite powders of EN AW 6061 aluminium alloy matrix reinforced with 5, 10 and 15 wt.% of titanium aluminide were produced by high-energy ball milling using an centrifugal high-energy ball mill (Fritsch GmbH, model ‘Pulverisette 6’) with the following parameters: ball-to-powder weight ratio: 6:1; ball diameter: 20 mm; ball material: AISI 420 quenched stainless steel; speed 700 rpm. A total of 1% (wt.) of microwax was added to control the process (PCA). No atmosphere controle gase was used. The high-energy milling time was the time necessary to complete the mechanical alloying process, from the point of view of the phenomenological aspects, determined for each composition.

The mechanically alloyed powders were characterised by their apparent density (MPIF Standard 28), flow - ability, morphology and microstructure (SEM, LM) and microhardness (Vickers, 50mN load).

3. Results and discussion

As previously mentioned, the main process which takes place in a mill during the MA method to produce quality powders with controlled microstructure is the repeated welding, fracturing, and rewelding of a mixture of powders. The morphology of the initial powders is modified when they are subjected to ball collisions. It is worth noting that the effects of collisions on the milled powders depend on the type of the constituent particles.

It has been shown that the initial ball-powder-ball collision causes the ductile metal powders to flatten and work harder when they are cold welded and heavily mechanically deformed. They are brought into intimate contact, forming layered structure of composite particles consisting of various combinations of the starting ingredients, as schematically shown in Figure 3.

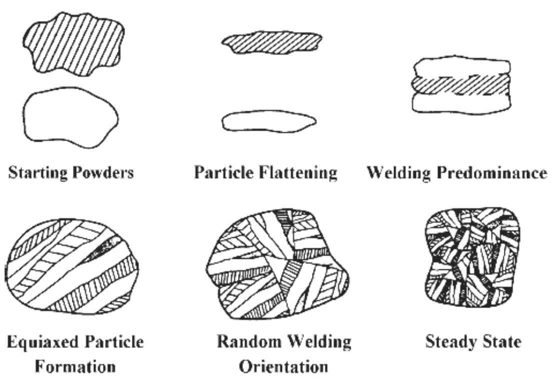

Fig. 3. Evolution of different stages of mechanical alloying of a ductile - ductile system according to [12]

Further milling results in cold welding and deformation of the layered particles and a refined microstructure is obtained. Due to the initially low hardness of the starting elemental powders, the lamellar spacing of the agglomerated particles are quickly reduced upon further milling. Increasing the MA time increases the hardness and this leads to fracturing of the agglomerated powders into smaller particles. In the following stage, the welding predominates, causing the equiaxed particle formation. Then welding and fracture mechanism reach equilibrium and the formation of particles with randomly oriented interfacial boundaries. The final stage is characterized by the steady state process, in which the microstructural refinement can continue, but the particle size and size distribution remain approximately the same.

The result obtained with the EN AW 6061 with presence of intermetallics particles submitted to high energy mechanical milling/alloying, are in good agreement with these description. The predominantly spherical or equiaxial morphology of the initial (as received) powders, allows good powder packing, which results in the high initial apparent density values. The laminar morphology of the shorter-time mechanically milled powders brings poorer powder packing, and consequently decrease in the apparent density values. In a later stage of the process, the morphology of the particles will change again to an equiaxed one, with better powder packing and an increase in the apparent density. Confirmation regarding morphology and microstrucutre evolution described above gives morphology and microstructure analysis of the powder particles carried out in SEM. After short milling times, 2, 4 and 6 h, there is a predominance of deformed – flat particles (Figures 4 and 5).

Important is to notice that intermetallics particles undergo plastic deformation and with more frequency fragmentation. Then, when ductile particles start to weld, the brittle particles come between two or more ductile particles at the instant of the ball collision. As a result, fragmented reinforcement particles will be placed in the interfacial boundaries of the welded metal particles, and the result is the formation of a real composite particle. After 8, 10 and 12h of milling time, welded particles are observed with more frequency (Figure 6), which indicates that welding is the predominant phenomenon at this stage of milling. As welding is the predominant mechanism in the process, the particles change their morphology by piling up the laminar particles.

These phenomena, deformation, welding and solid dispersion, harden the material and increase the fracture process, which also contributes to the equiaxed morphology. Welding and fracture mechanisms then reach equilibrium, promoting the formation of composite particles with randomly orientated interfacial boundaries. Figures 7 and 8 presents the morphology and microstructure of composite powder particles at the steady state after 18 h of mechanical alloying.

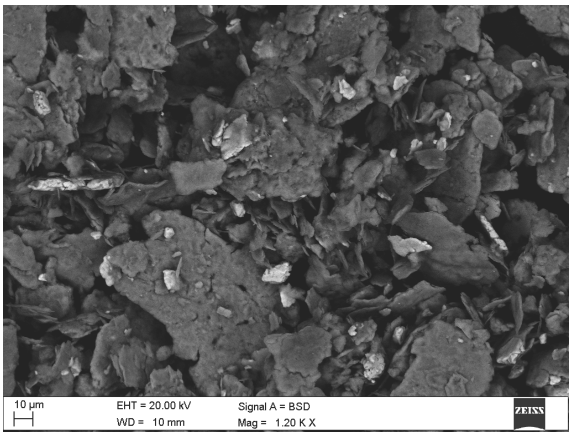

Fig. 4. Morphology of EN AW6061 powders with 15% of Ti_3Al reinforcement after 6 h of mechanical alloying, SEM

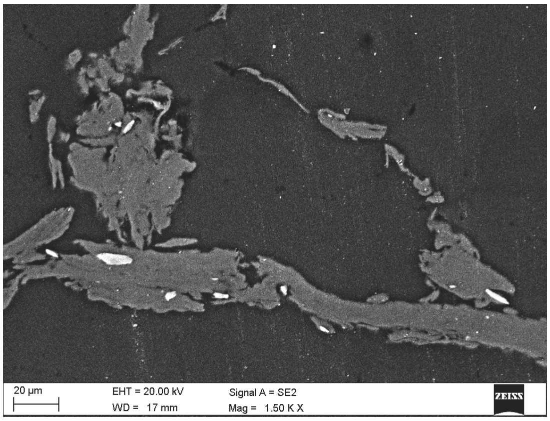

Fig. 5. Microstructure of EN AW6061 powders with 15% of Ti_3Al reinforcement after 6 h of mechanical alloying, SEM

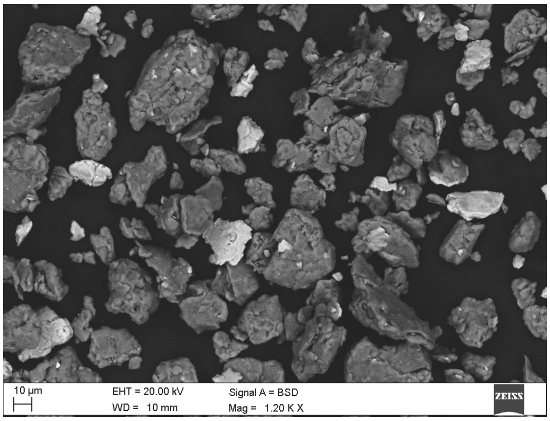

Fig. 6. Morphology of EN AW6061 powders with 15% of Ti_3Al reinforcement after 12 h of mechanical alloying, SEM

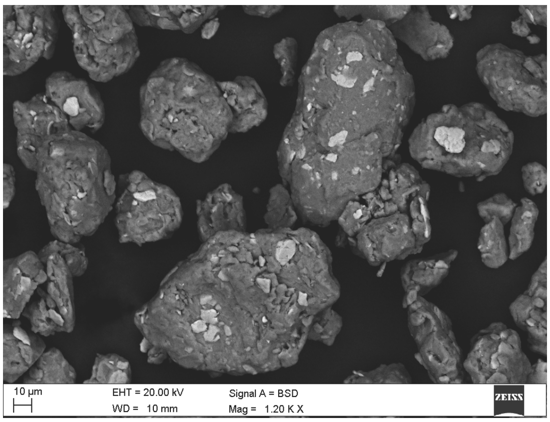

Fig. 7. Morphology of EN AW6061 powders with 15% of Ti_3Al reinforcement after 18 h of mechanical alloying, SEM

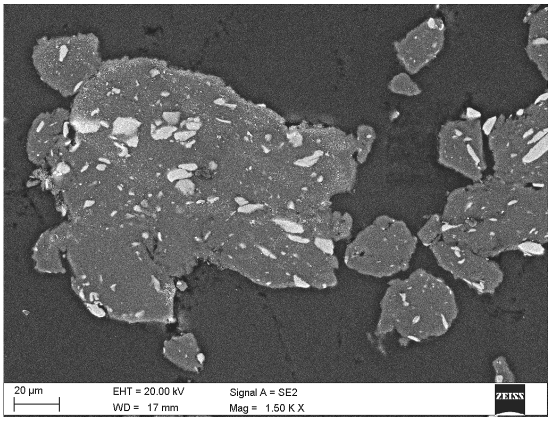

Fig. 8. Microstructure of EN AW6061 powders with 15% of Ti_3Al reinforcement after 18 h of mechanical alloying, SEM

In the processes applied widely in the PM manufacturing there are requirements for different particle size and flow characteristics. Difference in morphology is seen in the different flow and apparent density results. The apparent density is the mass per unit volume of a material including voids inherent in the as tested material. In the case of powder materials, the apparent density expresses the density without the application of pressure. The first point observed in the high-energy process is the dependence of milling time on apparent density. Figure. 9 shows exemplary dependence for the EN AW 6061 matrix composite reinforced with 15 % of titanium aluminide intermetallic particles. Zero hours of milling time means the apparent density of the as-supplied powder in the case of the unreinforced metal alloy. With short milling times, there is a continuous decrease in the apparent density with increasing milling time; it reaches a minimum value at 6 h of milling time, about one third of the initial value, and then starts to increase with increasing milling time. After longer milling, 16 to 18 h, depending on volume fraction of reinforcing particles the apparent density reaches a steady value, similar to that of the as-received powder. There is, however not a big one, influence of intermetallics particles fraction (in the investigated range) on the steady state appearance. This effect is greater – shorter milling time needed, with a higher percentage of Ti_3Al (15%) as reinforcement material.

Table 3 presents results of apparent density measurements and flow rate for powders at steady state, after 18 h of mechanical alloying and for initial aluminium alloy powders. Results of apparent density measurements indicates better packing efficiency of composite powders in comparison with unreinforced powders, however incorporation of second phase with higher density must not be forgotten. On the other hand recuperation of flowability and their increase for higher percentage of Ti_3Al reinforcing particles indicates that composite powders have better particles size distribution achieved by removal of fine size fraction and irregular in shape particles typical for air atomized powders.

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Applying mechanical alloying route of composite powders production, makes it possible to obtain diminution of reinforcing particles size as well as homogenous reinforcement particles distribution. As was expected mechanical milling process has improved the reinforcement distributions throughout the whole particle (Fig. 7 and 8). Observed changes in the microstructure, influence on the mechanical properties of composite particles obtained. Microhardness measurements results of as received powders and mechanically milled, with different volume fraction of reinforcing particles powders, are presented in Table 4.

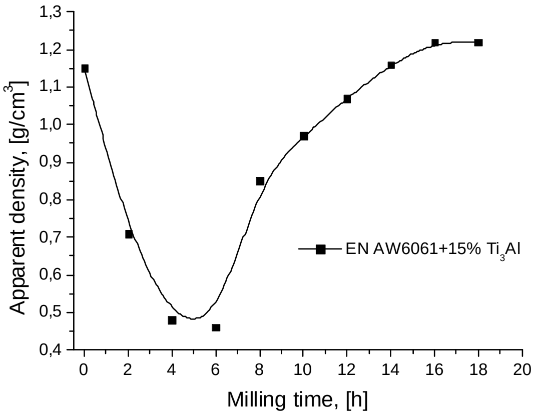

Fig. 9. Apparent density changes versus time of mechanical alloying for EN AW6061 powders with 15% of Ti_3Al reinforcement

Table 3.
Apparent density and flow rate measurements results

Powder type	Apparent density [g/cm^3]	Flow [s]
EN AW6061	1.16	Not flowing
EN AW6061 +5%Ti_3Al	1.18	4.13
EN AW6061 +10%Ti_3Al	1.20	4.02
EN AW6061 +15%Ti_3Al	1.22	3.96

Table 4.
Microhardness measurements results for investigated powders

Powder type	Microhardness HV	Standard deviation
EN AW6061	75.9	10.1
Ti_3Al	431.1	48.6
EN AW6061 +5%Ti_3Al	181.4	12.3
EN AW6061 +10%Ti_3Al	188.7	16.2
EN AW6061 +15%Ti_3Al	198.8	19.2

4. Conclusions

The main conclusion based on researches carried out are:

- The EN AW 6061 aluminium alloy powder with presence of intermetallics powder particles submitted to high energy mechanical alloying, are in good agreement with the model description proposed for ductile - ductile materials.
- The apparent density changes versus milling time can be used to control the composite powders production via mechanical alloying.
- The presence of reinforcements particles accelerates the mechanical alloying process.
- Mechanical alloying improves the distribution of the Ti_3Al intermetallic reinforcing particles throughout the aluminium matrix, simultaneously reducing their size.
- Observed microstructural changes influence on the mechanical properties.
- Microhardness measurements of composite powders indicates their increase in comparison to the initial state of aluminium alloy powders.

Acknowledgements

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