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Microstructural characterisation of EN AW6061 alloy matrix composites with Ti_3Al intermetallics reinforcement

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Properties

ABSTRACT

Purpose: The main aim of this work is to investigate microstructure of EN AW6061 matrix composites with Ti_3Al intermetallics reinforcement produced by powder metallurgy techniques and hot extrusion.
Design/methodology/approach: Microstructure observations of 5 mm diameter extruded bars were made by light microscopy, scanning electron microscopy, and transmission electron microscopy.
Findings: Extruded composites are characterized by a very homogeneous distribution of intermetallic particles and with good cohesion at the matrix /particle interfaces.
Research limitations/implications: Contributes to research on microstructural characteristics of aluminium alloy matrix composite material reinforced with intermetallics phase.
Practical implications: Conducted research shows that applied technology of composite materials production allows to obtain very good microstructural characteristics.
Originality/value: New approach for production of composite materials with homogeneous microstructure.
Keywords: Mechanical alloying; Aluminium matrix composites; Intermetallics; Microstructure

1. Introduction

Among all metal matrix composites (MMC) aluminium could be the most widely used metal as matrix due to its low density combined with high stiffness. It is valid especially in the aerospace and aeronautical industries. Aluminium matrix composites (AMC) were designed with the aim to conjugate the desired characteristics of two or more materials with the ability to withstand high tensile and compressive stresses by the transfer and distribution of the applied load from the ductile matrix to the reinforcement phase. There are several different manufacturing methods which can be applied for this class of composites. In principle, because of better specific strength, continuously reinforced materials have been more investigated and the effort involved in their development has been higher than for other composites. Unfortunately, their wide industrial application is limited by costs of high strength fibres and its processing methods as well as many times lack of secondary forming processes they must be used in the original shape in which they were manufactured. On the other hand non-continuously reinforced composites do not have the same level of properties as continuously reinforced but their costs is lower, their processing methods are more adaptable to conventional ones and their performance is acceptable. A critical step in the processing of metal matrix composites reinforced with particles is the insertion of these particles into the metal matrix alloy. This greatly influences the strength of the composite since it is controlled by

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the metal-particle interfacial bond strength. Powder extrusion consolidates the composite to over 98% dense, and can be carried out below the solidus temperature of the alloy. The most important aspect of the microstructure is the distribution of the reinforcing particles, and this depends on the processing and fabrication routes involved, as well as the relative size of the matrix and reinforcing particles. Extrusion can homogenize the structure to some extent, but minimizing reinforcement inhomogeneity during initial processing is important to achieve optimum properties [1-14].

The main aim of this work is to investigate microstructure of EN AW6061 matrix composites with Ti_3Al intermetallics reinforcement produced by powder metallurgy techniques and hot extrusion.

2. Materials and methods

Aluminium matrix composites were produced employing the atomised aluminium alloy AA6061 as metal matrix when Ti_3Al intermetallics particles were used as reinforcement. The composite powders were produced by high-energy ball milling in planetary ball mill Fritsch Pulveriset during 18 h. Three sets of samples with 5, 10 and 15 wt.% of reinforcement were prepared. The powders were cold pressed in the cylindrical matrix 25mm in diameter with 300MPa pressure and then extruded at 500–510°C with graphite as lubricant without caning and degassing. Extruded bars of 5mm diameter and near theoretical density were obtained. Microstructure observations were made by light microscopy Leica MEF 4A, scanning electron microscope SEM, and transmission electron microscope JEOL JEM 3010, TEM.

Thin foils of investigated composites were prepared by mechanical pre thinning, followed by low angle ion polishing realized in Gatan PIPS™ high milling rates unit.

The microstructure examination and diffraction investigations of phase composition of the thin foils were made on the transmission electron microscope at the accelerating voltage of 300 kV. The diffraction patterns from the transmission electron microscope were solved using a computer aided program.

3. Results and discussion

Applying PM route of composite materials production, makes it possible to obtain homogenous reinforcement particles distribution without typical for conventional casting processes segregation. As it was expected mechanical milling process has improved the reinforcement distributions throughout the whole composite powder particles Figure 1. It can be seen that the mechanical milling has improved the reinforcement distributions throughout the whole particle, and has produced equiaxial morphology of composite powder particles. Additionally intermetallic particles has undergone plastic deformation as well as the fragmentation resulting in diminutions of reinforcing particles size.

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. In the mechanically milled composites one can see very fine distribution of small reinforcement particles and absence of agglomerates. Based on the observation made also on the scanning electron microscope one can see good bond between the intermetallic and matrix. This was also confirmed by the absence of decohesion between reinforcements and matrix on tensile fracture surfaces [1].

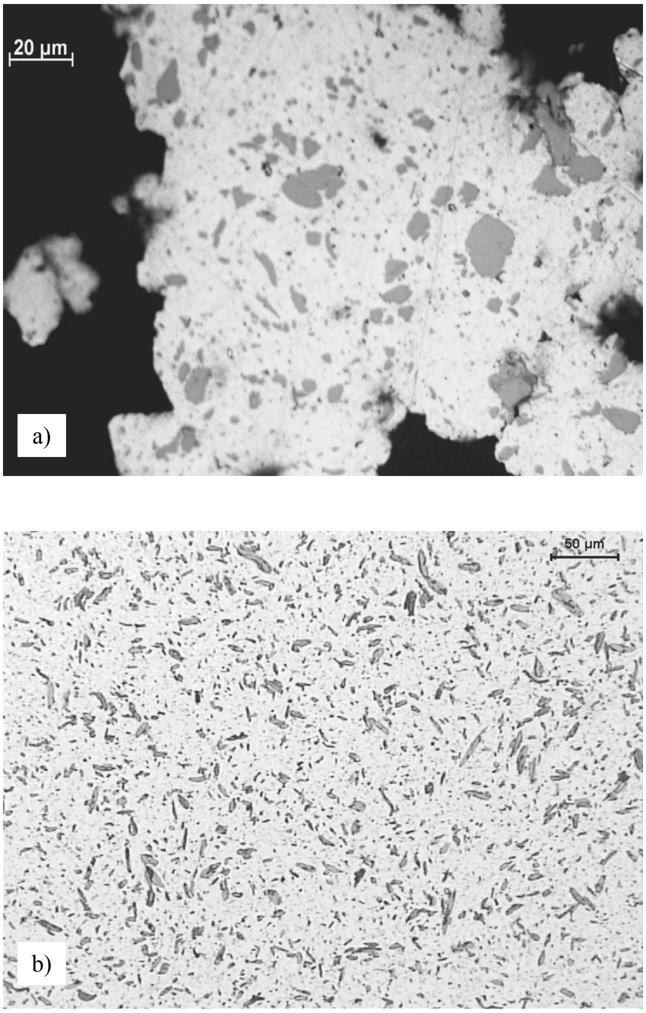

Fig. 1. Microstructure of EN AW 6061 + 15% Ti_3Al reinforcing particles, a) composite powder particle after 18h of mechanical alloying, b) microstructure of extruded composite materials, LM

Selected results of investigations in transmission electron microscope (TEM) of thin foils prepared from extruded bars of investigated composite materials based on aluminium alloy EN AW6061 reinforced with Ti_3Al intermetallic are presented in Figures 2-4.

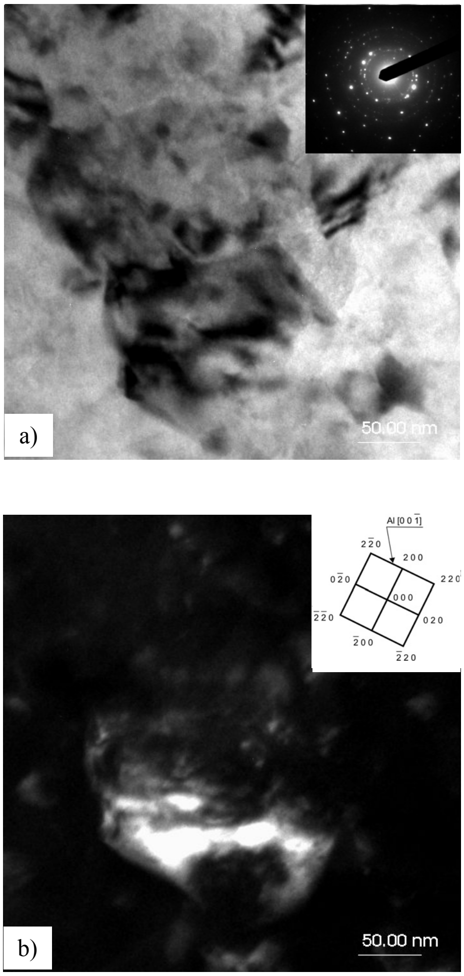

Fig. 2. Microstructure of thin foil for composite material EN AW6061+15%Ti_3Al, a) bright field micrographs with selected area diffraction pattern, b) dark field micrographs from diffraction spot ($\bar{2}\ \bar{2}\ 0$) α-Al and solution of the diffraction pattern

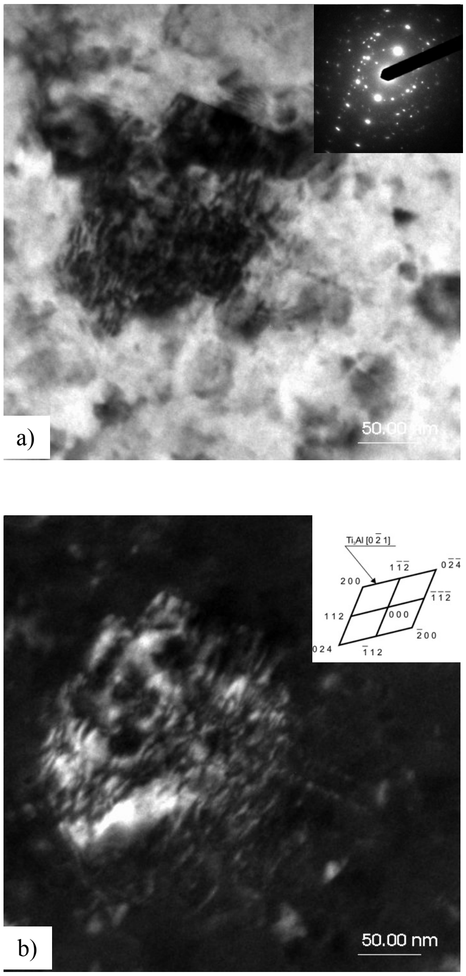

Fig. 3. Microstructure of thin foil for composite material EN AW6061+15%Ti_3Al, a) bright field micrographs with selected area diffraction pattern, b) dark field micrographs from diffraction spot ($\bar{1}\ 1\ 2$) Ti_3Al and solution of the diffraction pattern

As expected predominant phase observed during thin foils examination is the fine grained α– Al based solid solution. Fig. 2 shows bright and dark field micrographs, selected area diffraction patterns and solution of the diffraction patterns.

Among the α-Al solid solution phase presence of Ti_3Al intermetallic phase can be easily detected. Fig. 3. shows exemplary micrographs for Ti_3Al particle. Solution of selected area diffraction pattern confirm that observation and indicates that intermetallic phase is crystallizing in crystal lattice I4mmm. Also this images confirm that intermetallic phase is well bonded with aluminium matrix.

Beside of those findings presence of fine precipitates of Al_2O_3 oxide phase can be observed (Fig.4). Obviously very fine powders have relatively large surface areas and, thus, are highly reactive with oxygen, during air atomisation process of initial powders but also during composite powders production process with mechanical alloying.

4. Conclusions

The analysis of the investigation results of microstructure of hot extruded composite materials based on EN AW6061 aluminium alloy reinforced with Ti_3Al intermetallics phase shows:

- The ball milling in planetary mill leads to homogeneous reinforcement particle distribution throughout aluminium matrix alloy creating composite powder particles,
- Based on metallographic examination extruded composites are characterized by a very homogeneous distribution of intermetalic particles and the absence of any reaction and with good cohesion at the matrix /particle interfaces.
- TEM examination of thin foils as well as selected areas diffraction pattern solution confirms complex microstructure of investigated materials,

- Preliminary analysis of this images confirm presence of α-Al solid solution matrix phase, Ti_3Al intermetallic reinforcing phase and fine precipitates of Al_2O_3 oxide phase

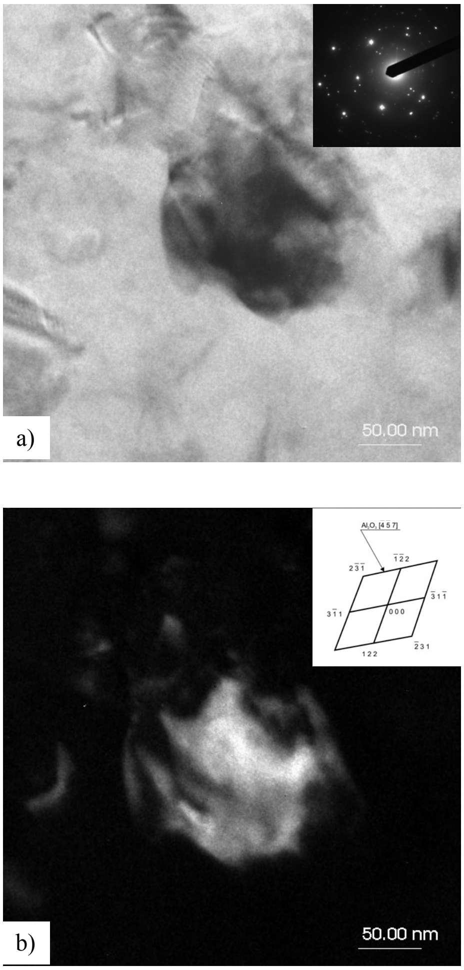

Fig. 4. Microstructure of thin foil for composite material EN AW6061+15%Ti_3Al, a) bright field micrographs with selected area diffraction pattern, b) dark field micrographs from diffraction spot (1 2 2) Al_2O_3 (R3c) and solution of the diffraction pattern

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