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Characterization of aluminium matrix composites reinforced by Al–Cu–Fe quasicrystalline particles

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ABSTRACT

Aluminium matrix composites were consolidated from elemental Al powder and atomised $Al_{65}Cu_{20}Fe_{15}$ particles by vacuum hot pressing technique. The spherical $Al_{65}Cu_{20}Fe_{15}$ particles consisted of icosahedral quasicrystalline dendrites or cells and cubic τ-AlCu(Fe) phase located in interdendritic areas. The composites with different content of the reinforcement particles (20, 40 and 60 wt%) were prepared. All composites showed density about 99% and a good bonding between the $Al_{65}Cu_{20}Fe_{15}$ particles and the matrix. It was shown that the phase composition of the atomised particles did not change after consolidation for the composite containing 20% and 40% added particles while Al_2Cu precipitates formed at the Al/$Al_{65}Cu_{20}Fe_{15}$ interfaces and inside the matrix in the composite with 60% of $Al_{65}Cu_{20}Fe_{15}$ particles. With the increase of the volume fraction of the reinforcement in the composite the hardness as well as compressive strength increased reaching the value of 173 $HV_{0.5}$ and 370 MPa, respectively for 60% of $Al_{65}Cu_{20}Fe_{15}$ particles. The friction coefficient slightly varied in the range 0.5–0.7 depending on the composition.

1. Introduction

Quasicrystals are the solids with quasi-periodic atomic structures and crystallographic symmetries forbidden to ordinary periodic crystals. Because of the special structure quasicrystals possess unique physico-mechanical properties. The mechanical properties such as high strength and hardness, high elastic modulus, low friction coefficient [1,2] are very promising in industrial application but high brittleness are the main disadvantages to applied quasicrystals as material in bulk shape. For this reason quasicrystals could be utilized in the form of coatings or as strengthening phase in alloys and composites. The stable Al–Cu–Fe quasicrystals are more attractive compare to the other systems because non toxic and low cost components [3].

Aluminium based composites containing Al–Cu–Fe quasicrystalline particles were obtained first time by hot pressing aluminium powder and mechanical milled $Al_{64}Cu_{24}Fe_{12}$ alloy [4]. It was shown that the hardness of these composites increased almost 5 times compared to pure aluminium. In the next studies the powder metallurgy [5–10] or molten metal methods [11,12] were applied for synthesis the composites reinforced by Al–Cu–Fe quasicrystals. For all investigated composites the significant increase of mechanical properties was observed. It was also found that depending on the processing temperature, the quasicrystal is preserved in the composite or transforms to crystalline phases. Formation of the ω-Al_7Cu_2Fe phase was observed in the powder samples consolidated above 723–873 K [4,9,10]. A variety of phases such as Al_2Cu, Al(Cu, Fe) and $Al_{13}Fe_4$ were identified in the case of composites prepared by adding Al–Cu–Fe quasicrystals to the molten aluminium [11,12].

The aim of the study was characterization of the Al-based metal matrix composites reinforced by Al–Cu–Fe atomised powder produced by hot pressing.

2. Experimental

The $Al_{65}Cu_{20}Fe_{15}$ (in at.%) powder and aluminium powder (Alfa Aesar) of purity 99.5% were used to prepare the composites. The $Al_{65}Cu_{20}Fe_{15}$ powder was prepared by gas atomization device under argon using rayleigh-plateau forces in primary mode. Nanoval system which used a De Laval nozzle to atomise liquid was applied. As a result, fine to medium sized metallic powder with ball-shaped particles was produced [13]. The morphology of atomised $Al_{65}Cu_{20}Fe_{15}$ powder (QC) was spherical with the average diameter of 17.4 μm [14]. The powder consisted of the icosahedral quasicrystalline i-phase dendrites and small amount of τ-Al(Cu, Fe) cubic phase in interdendritic areas. Aluminium powder of average particle size in the range 7–15 μm was mixed with various amount of $Al_{65}Cu_{20}Fe_{15}$ powder (QC = 20, 40 and 60 wt% corresponding to 13.6, 29.5 and 48.5 vol.%, respectively) using ball milling. Milling was performed in planetary high-energy mill Fritsch-P5 in an argon atmosphere with rotational speed 100 rpm by 0.5 h. The composites were

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prepared by the uniaxial hot pressing in vacuum at temperature 673 K by 10 min with maximum pressure of 600 MPa. The pure aluminium powder was consolidated as a reference sample.

The microstructure of composites was examined by X-ray diffraction (XRD) using a Philips PW 1840 X-ray diffractometer with Cu Kα radiation (λ = 1.5406 Å), scanning (SEM) and transmission (TEM) electron microscopy using FEI scanning electron microscope E-SEM XL30 and FEI transmission electron microscope Tecnai G^2 operating at 200 keV and equipped with high-angle annular dark field detector (HAADF-STEM) combined with energy dispersive X-ray (EDX) EDAX microanalysis. Tenupol-5 double jet electropolisher was used for the thin foil preparation in an electrolyte containing nitric acid and methanol (1:3) at the temperature of −30 °C and voltage of 15 V. The porosity of the composites has been estimated from the SEM-SE images of the cross-section of the compacted samples. The image analysis software Image J [15] was used to measure the percentage amount of the pores in the samples. Hardness of the composites was measured with the load of 5 N using CSM Instrument with Vickers indenter (7–10 measurements have been made for each sample). Compression tests were carried out using INSTRON 6025 testing machine modernized by Zwick/Roell company. Friction properties were investigated with ball-on-disc tribometer. Friction tests were carried out in air (temperature 23 °C) and under non-lubricant conditions using 6 mm diameter WC ball. The sliding velocity was 0.1 m/s and the normal load was 2 N.

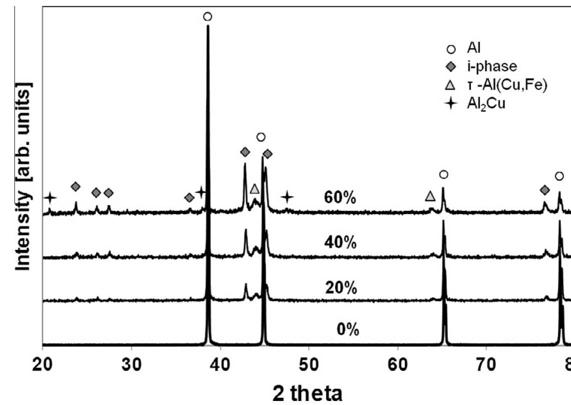

Fig. 2. X-ray diffraction patterns of the composites containing 20%, 40% and 60% of $Al_{65}Cu_{20}Fe_{15}$ powder and the reference sample of compacted pure Al powder.

3. Results and discussion

The microstructures of the cross-section of the composites reinforced with different amount of $Al_{65}Cu_{20}Fe_{15}$ powder are presented in Fig. 1. The spherical QC particles are uniformly distributed in the Al matrix for all compositions. For all investigated composites the contribution of the pores measured from the SEM-SE images was about 1%.

Fig. 2 shows the X-ray diffraction patterns of the composites. The peaks of aluminium face-centred cubic phase, the icosahedral i-phase and cubic τ-Al(Cu, Fe) phase are indentified for the composites containing 20% and 40% of QC particles. Detection only two phases besides Al solid solution indicated that the phase composition of the $Al_{65}Cu_{20}Fe_{15}$ particles is similar to the initial atomised powder before compaction. The additional reflections of the Al_2Cu phase were found for the composite with 60% of QC particles, although the both i-phase and τ-Al(Cu, Fe) are also present. It means that increase the amount of the QC particles in the composites leads to partial transformation of the phases present in atomised powder.

The TEM examination revealed that Al_2Cu phase is located in the interface of the QC particles and the matrix. In Fig. 3 the bright-field image shows the Al_2Cu phase close to the spherical QC particles. The electron diffraction patterns and the result of

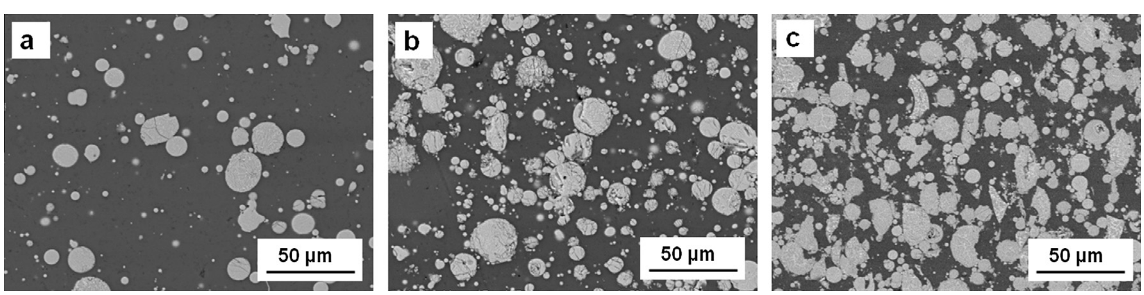

Fig. 1. SEM images of the cross-section of the composites with (a) 20%, (b) 40% and (c) 60% of $Al_{65}Cu_{20}Fe_{15}$ powder.

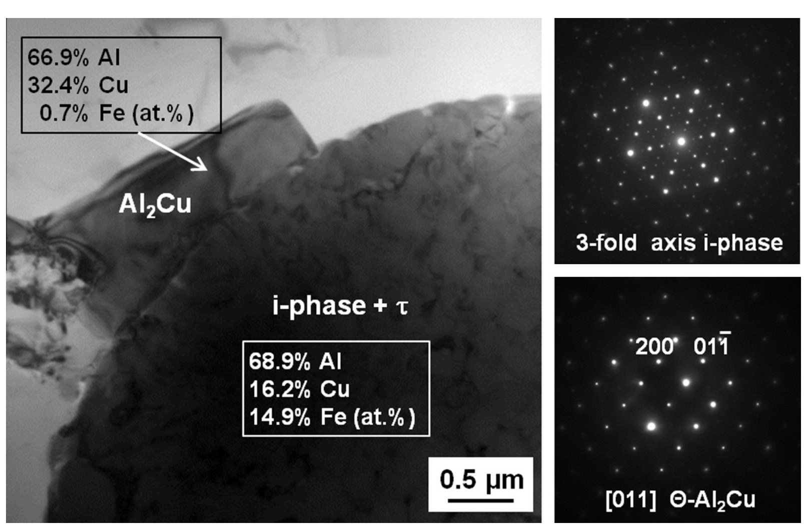

Fig. 3. TEM bright-field image and corresponding electron diffraction patterns of 3-fold symmetry of i-phase and θ-Al_2Cu phase ([011] zone axis) for the composite containing 60% of $Al_{65}Cu_{20}Fe_{15}$ powder.