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Structure study of $Al+Al_2O_3$ composite by atomic force microscopy

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The structure of a metal matrix composite based on aluminum containing 6, 17 and 24 wt % Al_2O_3 was studied by atomic force microscopy. The composite was prepared by the method of magnetic-pulse compaction from aluminum nanopowder obtained by the electric wire explosion method. The samples compacted at 400 ° C have more clearly expressed grain boundaries than those obtained at room temperature. The structure of a composite subjected to dynamic plastic deformation is studied.

Keywords: metal matrix composite, scanning probe microscope, atomic force microscopy, electric wire explosion, magnetic pulse compaction, dynamic plastic deformation.

Introduction

Metal-matrix composite (MMC) based on aluminum with a strengthening phase of aluminum oxide is considered to be a promising material for structural applications worldwide, for example, MMC is used in the aerospace, defense and automotive industries [1-7]. It should be noted that the material itself and the technology of its production are constantly being improved [8-12].

MMC, characterized by high strength and low density, is considered as a competitor to aluminum alloys, for example, in the aerospace industry. To improve the strength of aluminum, the following methods are used: introduction of additional phases into the metal matrix [11] and scaling down the structure of the final part to a nanoscale [13]. Both methods improve the mechanical properties of the composite, for example, hardness and tensile strength [14]. The high strength of MMC is ensured by the nanostructure, and its preservation ensures the volume distribution of the solid phase-aluminum oxide particles, including at high-temperature heat treatment. In order to create nanostructured materials, either source nanosized powders or methods of processing of metals based on the use of dynamic plastic deformation (DPD) [15, 16], are used.

In the Institute of Electrophysics of the Ural Branch of the Russian Academy of Sciences a technology for obtaining a nanostructured material by the methods of electric wire explosion (EWE) [17] and magnetic-pulse compaction (MPC) was previously proposed [18-20]. The samples obtained were characterized by 2-3 times higher, hardness and thermal stability, in comparison to metallic aluminum, but did not have a very high tensile strength. One of the promising ways to improve the strength properties of metals is considered to be DPD.

In this paper, we present the results of the study of the structure of aluminum-based metal matrix composite containing 6, 17 and 24 wt % Al_2O_3, depending on the composition and the conditions for obtaining (oxide-metal ratio and pressing temperature) obtained by EWE and MPC methods, as well as subject to dynamic plastic deformation.

Results and Discussion

Aluminum nanopowders with different content of aluminum oxide were obtained by EWE method in a mixture of argon and oxygen. An important feature of the powder particles obtained by this method (with an average diameter of $\approx$ 80 nm) is the formation of a 2 to 5 nm thick shell of amorphous aluminum oxide on their surface that protects the particle from further oxidation. The oxide content in MMC was varied in the range of (5-24) wt. %.

Magnetic pulse compaction was carried out by a single pressure pulse with an amplitude of 1.4 GPa at room temperature and 400 $^\circ$ C after preliminary degassing by evacuation (residual pressure $\approx$ 10 Pa) when heated to the pressing temperature.

To implement the DPD mode, each sample, except for reference ones was pressed twice by magnetic pulse pressing. The first act of pressing was carried out in a matrix with a diameter of 8 mm, the second in a 10 mm diameter die. At the same time, the pressure and temperature of pressing varied in the ranges (1.4-1.8) GPa and (20-400) $^\circ$ C, respectively.

A structure study of composites was carried out on a scanning probe microscope Solver P47 (NT-MDT) using atomic force microscopy (AFM). Surface topography was measured using AFM in semi-contact scanning mode. Studies of the structure were carried out on the cleaved facets MMC based on Al with various additions of Al_2O_3.

The scan was performed with a NSG 20S probe with a tip curvature radius of $<$ 10 nm, a force constant of 48 N/m and a resonant frequency of 420 kHz (NT-MDT). Based on the results obtained, a range of average grain sizes of each composite was determined. An increase of Al_2O_3 concentration is accompanied by a decrease in the grain size in the composite structure at both pressing temperatures.

From the images of the surface structure (Figure 1), it is possible to trace the oxide phase area increase (lighter areas in the phase-shift mode) with the growth of the oxide additive in the composite, and, accordingly, the predominance of the metallic phase (darker regions) with the minimum content of Al_2O_3.

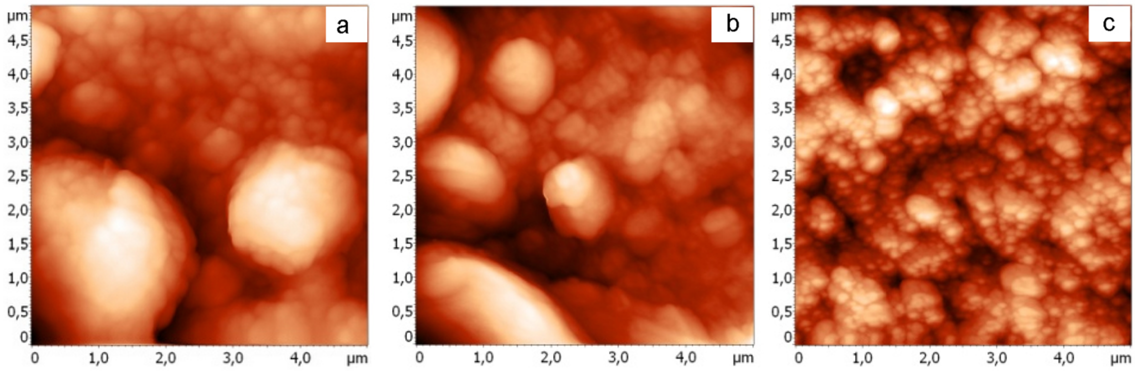

Figure 1. AFM image of the surface of a composite pressed at room temperature, with different contents of aluminum oxide: a-6 wt. % Al_2O_3, b-17 wt. % Al_2O_3, and c-24 wt. % Al_2O_3.

According to the images of structure of composites compressed at 400 °C (Figure 2), it can be noted that the faceting of grains became visible, in contrast to those compressed at room temperature, which simplified the analysis of the picture as a whole and the processing of the results.

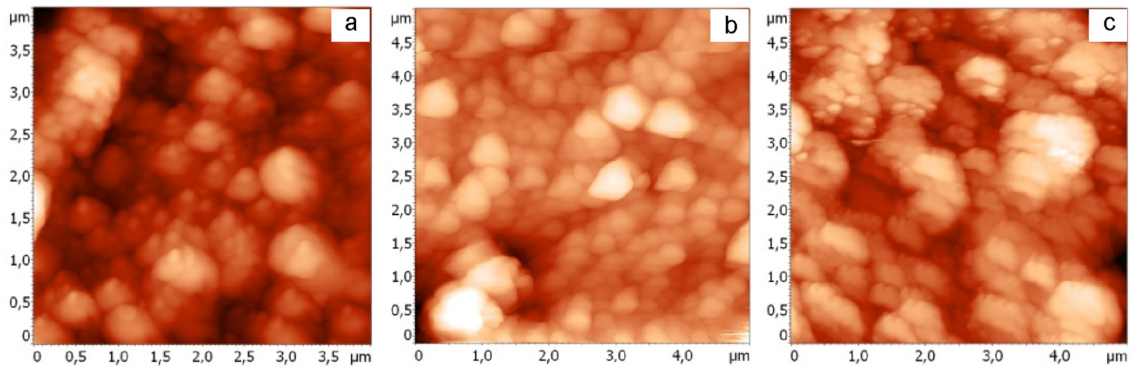

Figure 2. AFM image of the surface of a composite pressed at 400 °C, with different contents of aluminum oxide: a-6 wt. % Al_2O_3, b-17 wt. % Al_2O_3, and c-24 wt. % Al_2O_3.

The microstructure of composites that differ in composition but are pressed at the same temperature has no noticeable differences (Figure 3). The grain size of composites compressed at room temperature (450 ± 50 nm) does not differ from those compressed at 400 °C (500 ± 60 nm) within the measurement error.

When studying the structure of MMC before and after dynamic plastic deformation, a significant change in their microstructure was observed. After the first pressing step (U_1 = 1 kV), the MMC structure is characterized by elongated grains, and after repeated pressing in a larger diameter matrix, as a result of strong plastic flow (bulk material transfer) into the existing voids of the pressure tool, grains close to spherical with an average grain size of the order of 150 nm. A similar picture was observed for samples with U_1 = 1.8 kV, as well as in the case of high-temperature pressing, with the exception of the mean grain size, which in

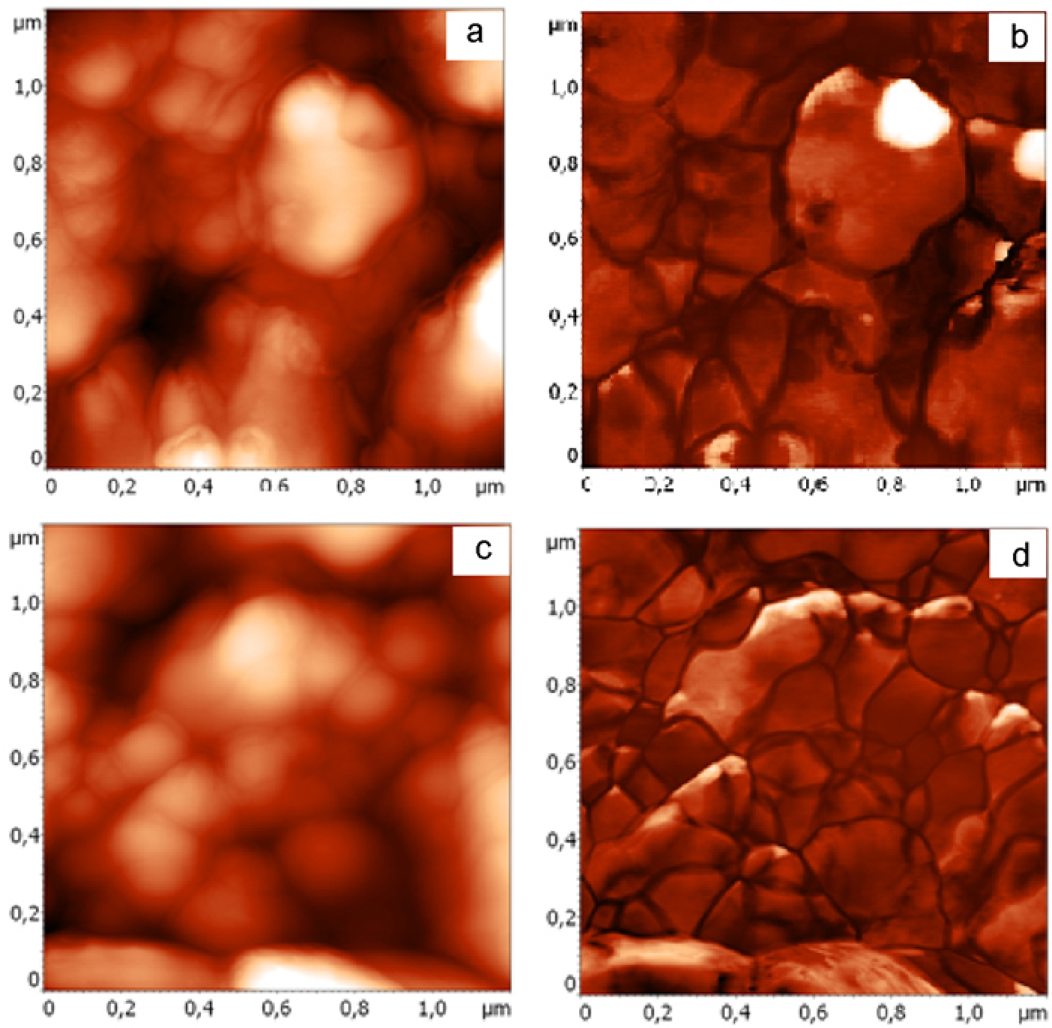

Figure 3. AFM images of the surface of a composite with a content of 6 wt % Al_2O_3 : a (height), b (phase) - room. temp., c (height), d (phase) - 400 ° C.

this case was ≈ 300 nm. It is important to note that with such a high degree of deformation of the microstructure, the samples retain their integrity throughout the volume, that is, they have high strength.

Conclusion

As a result of the investigation of the microstructure of the metal matrix composite obtained at two different pressing temperatures, it was found that in the samples pressed at 400 ° C the grains have clearly defined boundaries, in contrast to those pressed at room temperature with the same oxide phase content.

It was found that in the process of DPD less noticeable texturing of the microstructure formed during the first stage of magnetic pulse compaction. The grains of the deformed MMC are close to spherical ones with an average size of 150 nm (pressing at 20 ° C) and 300 nm (pressing at 400 ° C).

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