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STRUCTURE AND MECHANICAL PROPERTIES OF MAGNESIUM-BASED COMPOSITES REINFORCED WITH NITRIDE ALUMINUM NANOPARTICLES

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There are many up-to-date promising approaches to increase the properties of composites based on metals and alloys [1, 2]. It is known that the use of aluminum oxide particles makes it possible to create dispersion-reinforced magnesium composites with heterogeneous structure and high mechanical properties (tensile strength, Young's modulus, wear resistance, etc.) in a wide temperature range [3]. High mechanical properties are achieved by the obstacles to the dislocations motion and are determined by the size of aluminum oxide particles, the volume concentration, and the uniformity of their distribution in the magnesium matrix [4]. It is of great interest to use nano-sized aluminum nitride as reinforcing particles because of the higher specific strength and the low coefficient of thermal expansion in comparison to those of nano-sized aluminum oxide [5]. Thus, it seems relevant to study the effect that aluminum nitride nanoparticles have on the structure and mechanical properties of Mg–AlN composites.

The composites were prepared using the ML12 magnesium alloy (Fe – 0.01%, Si – 0.03%, Ni – 0.005%, Al – 0.02%, Cu – 0.03, Zr – 1.1%, Be – 0.001%, Zn – 5%, Mg – basis) as a matrix and nano-sized aluminum nitride powder (AlN) synthesized by the electrical explosion of wire (EEW) method [6]. According to TEM (Fig. 1*a*), the average aluminum nitride particle size was ~80 nm. The composites were produced using a standard permanent-mold casting technique, and the particles were introduced at casting into the melt jet with subsequent vibration treatment during its crystallization. The amount of the nanoparticles in the composites obtained was 0.75 and 1.5 wt%.

According to the microstructure analysis (Fig. 1*b*, *c*) of the composites obtained, there is a reduction in the average grain size to 230 and to 120 μm in the samples containing aluminum nitride (ML12 – 0.75 wt% AlN) and (ML12 – 1.5 wt% AlN), respectively in comparison with the ML12 base alloy (450 μm). The reduction of the structural elements size seems to be associated with the formation of new crystallization centers around nonmetallic inclusions and a considerable restraint of the crystal growth caused by their destruction by the subsonic impact arising in the vibration processing of the melt. The increase in the amount of particles up to 1.5 wt% provides more crystallization centers than at 0.75 wt%, thereby contributing to the grain refinement. At that, the average grain size is a constant value throughout the entire magnesium composite, which indicates the homogeneity of the nanoparticles distribution in the matrix. According to the measurement of the obtained materials' density, the base alloy porosity does not exceed 5%, while the nanoparticles introduction contributes to its increase up to 10%. It means that the increase in the composites porosity is caused by additional gases from the powder interparticle space, which penetrate the melt upon the nanoparticles introduction [2].

The mechanical tests of magnesium composites under tension (Fig. 2) showed the following. Despite the increase in the porosity, the introduction of 1.5 wt% of AlN nanoparticles into the ML12 alloy leads to simultaneous

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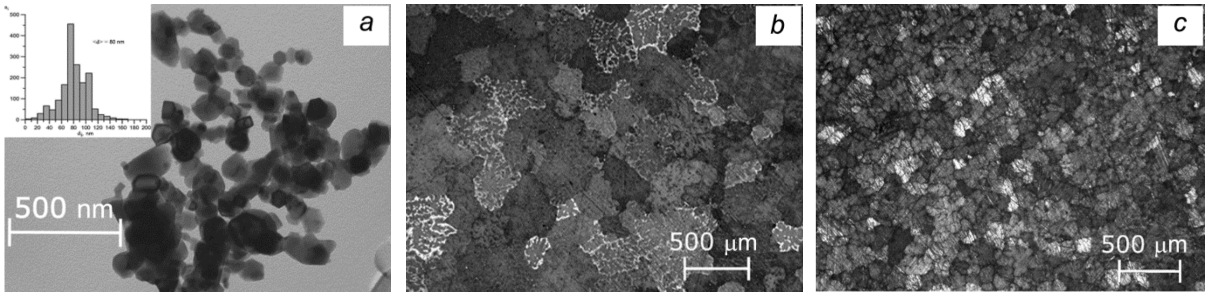

Fig. 1. TEM image of the aluminum nitride nanoparticles (*a*), the ML12 base alloy structure (*b*), and ML12+1.5 wt% AlN composite structure (*c*).

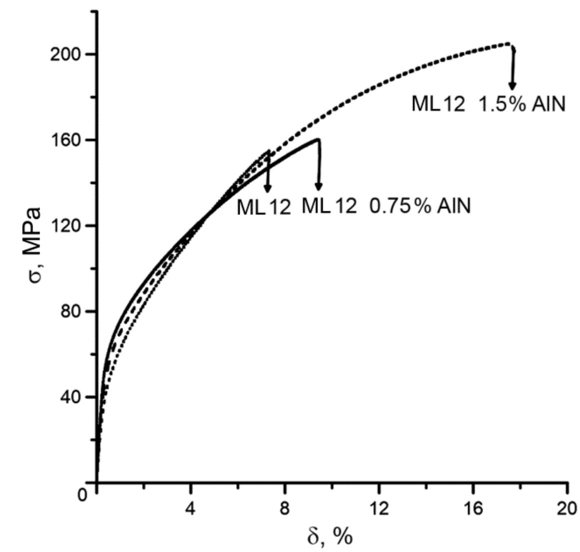

Fig. 2. Tensile test diagram of ML12-based composites with different amounts of AlN nanoparticles.

increase in the strength from 150 to 210 MPa and elongation from 7 to 18% respectively. At that, the composites hardness does not change and amounts to ~60 MPa. The increase in the mechanical properties of the ML12-AlN composites is apparently connected with the contribution of two mechanisms. The first one is the Orovan mechanism. It is implemented because the nanoparticles present in the soft metal matrix of the magnesium alloy become obstacles to the dislocations motion, and there is no particles "cutting", therefore the dislocation line curves. The second mechanism implementation seems possible owing to the Hall-Petch law [7, 8], which is based on the dependence of the material strength on the grain size, which decreases in the composites more than 3 times with respect to the base alloy.

Thus, the influence of aluminum nitride nanoparticles on the structure and mechanical properties of Mg–AlN composites was studied. The data obtained indicate that it is effective to use aluminum nitride nanoparticles for the production of magnesium-based composites with increased mechanical properties. Optical microscopy data indicate that 0.75 wt% of aluminum nitride nanoparticles leads to a significant reduction in the structural elements size, but does not contribute to any increase in the composites mechanical properties. At the same time, a larger amount of particles (1.5 wt%) can significantly increase the mechanical properties in comparison with those of the base magnesium alloy ML12.

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REFERENCES

1. S. A. Vorozhtsov, A. P. Khrustalyov, D. G. Eskin, S. N. Kulkov, and N. Alba-Baena, Russ. Phys. J., **57**, No. 11, 1485–1490 (2015).
2. S. A. Vorozhtsov, D. G. Eskin, J. Tamayo, *et al.*, Met. Mater. Trans. A., **46**, No. 7, 2870–2875 (2015).
3. W. Riehemann, Z. Trojanová, and A. Mielczarek, Proc. Eng., **2**, No. 1, 2151–2160 (2010).
4. L. Katsarou, M. Mounib, W. Lefebvre, *et al.*, Mater. Sci. Eng. A., **659**, 84–92 (2016).
5. M. N. Wahab, A. R. Daud, and M. J. Ghazali, Int. J. Mech. Mater. Eng., **4**, 115–117 (2009).
6. M. Lerner, A. Vorozhtsov, S. Guseinov, and P. Storozhenko, Metal Nanopowders Product. Character. Energetic Appl., 79–106 (2014).
7. N. J. Petch, Fracture, **1**, 376–420 (1968).
8. E. O. Hall, J. Mech. Phys. Solid., **1**, No. 4, 227–233 (1953).