Fabrication of samples and study on mechanical properties of metal matrix composites with system “Al-nanoAl₂O₃”

Y Chen, Yu А Kurganova, S P Shcherbakov and V K Gaaze
Department of Engineering Technology, Bauman Moscow State Technical University,
5/1, ul.Baumanskaya 2-ya, Moscow, 105005, The Russian Federation,
E-mail: chenyijin@yandex.ru

Abstract. Experimental samples of aluminum matrix composite materials filled with discrete Al₂O₃ fibers with a diameter of 10–20 nm were obtained by liquid-phase mechanical mixing. Copper powder with a diameter of 10 μm used as a transport component for the introduction of a light nanosized fraction. A comparative analysis of the hardness and microhardness of the experimental samples demonstrated the presence of a modifying effect from the introduction of discrete Al₂O₃ fibers.

Keywords: metal matrix composites, nanofibers of aluminum oxide, aluminum, liquid-phase method of mechanical mixing, mechanical properties

1. Introduction
Aluminum-composite materials (ACM) have a number of outstanding mechanical and functional properties, which allows them to be widely used both in Russia and in the world [1,2]. Recently, due to the development of nanotechnologies and technologies for producing ACM, Al₂O₃ nanofibers with a high level of elastic modulus and strength are considered one of the most promising materials that can be effectively used as fillers for ACM [3,4].

The main technological problems of introducing a discrete Al₂O₃ nanofiber into aluminum is overcoming the surface tension forces and ensuring the uniformity of their distribution. Analysis of scientific and technical literature [3-6] showed that an effective way to improve wettability is doping a matrix alloy or applying special coatings on the reinforcing phase. As the hypothesis of the experimental part of the research the use of copper as an effective component was accepted, which on the one hand can act as an alloying element, the effect of which on aluminum is well known, and on the other, an element that provides transport
functions when introducing nanofiber and enhancing the assimilation of the reinforcing phase by the matrix [3-4].

2. Experimental procedure
In this research, technical aluminum АД0 (GOST 4784-97), corresponding to 1050 ISO, which has the following chemical composition, % (by weight) is selected as a matrix:

|   | Al  | Si  | Fe  | Cu  | Mn  | Zn  | Ti  |
|---|-----|-----|-----|-----|-----|-----|-----|
|   | >99.50 | Up to 0.25 | Up to 0.25 | Up to 0.25 | Up to 0.25 | Up to 0.25 |

And as the filler there were used discrete nanofibers Al2O3 of the trademark “Nafen” with a diameter of 10-20 nm. Experimental samples of the composite material were fabricated using a liquid-phase method of mechanical mixing. To solve the problem of the bad wettability of Al2O3 aluminum fibers, micron powders of copper were used, which in turn improved the absorption and distribution of Al2O3 nanofibers in the matrix.

For comparative analysis, four compositions were melted under identical conditions: matrix (АД0), matrix with the addition of Al2O3 nanofibers (АД0+1.14%), matrix with transport powder (АД0+1.198% Cu) and matrix with Al2O3 on a copper transport powder (АД0+1.26% (Cu+Al2O3)).

3. Results and discussion
The microstructures of samples АД0, АД0+1.14% Al2O3, АД0+1.198% Cu, АД0+1.26% (Al2O3 + Cu powders) after etching, carried out on an Olympus GX51 microscope at 50x magnification, are shown in Fig.1. It is seen that after the introduction of Al2O3 nanofibers, the grain is decreasing. And using copper, decreasing is more efficient.

![Fig. 1 The microstructure of experimental samples after etching of АД0(a), АД0+1.14%Al2O3 (b), АД0+1.198%Cu (c), АД0+1.26% (Al2O3+Cu powders) (d)](image)

All samples were measured for Brinell hardness (GOST 9012-59) on a Struers automatic hardness tester with a load of 62.5 kg and a ball diameter of 5 mm. The analysis of the results (Table 1) demonstrates an increase in the hardness of samples with copper powders, which is evidently due to the formation of the hardening phase CuAl2. The introduction of Al2O3 nanofibre is not significant, but it reduces hardness. Compared with the hardness of the sample АД0 and the sample АД0+1.198% Cu, the hardness value of the samples АД0+1.26% (Cu+Al2O3) increases by 1.41 times and 1.20 times, respectively.

| Samples                        | Brinell Hardness (HBW) | Microhardness (HV) |
|--------------------------------|------------------------|--------------------|
| 1. АД0                          | 19.07±1.36             | 26.11±2.91         |
| 2.АД0+1,14% Al2O3               | 16.58±2.66             | 24.44±3.70         |
The results of measurement of microhardness of samples of AD0, AD0+1.14%Al2O3, AD0+1.198%Cu, AD0+1.26% (Al2O3 + Cu powders) on the automatic microhardness meter DURASCAN 70 with a load of 100 g were constructed microhardness distributions of the samples and given in Table 1. Compared to the microhardness of AD0, the value of the microhardness of the sample AD0+ 1.26% (Al2O3 + Cu powders) increases 1.22 times. The reduction in microhardness of AD0+ 1.14% Al2O3 is explained by the poor wettability of Al2O3 nanofibers with aluminum.

4. Conclusion

Thus, in the course of the work done, a method was developed and implemented for the effective introduction of discrete fibers of aluminum oxide with a diameter of 10–20 nm into the aluminum melt. The general laws of change in hardness and microhardness with a change in component composition are established. Thanks to the use of transporting copper powder with a diameter of 10 μm, it was possible not only to introduce nanofibers into the aluminum melt, but also to increase the hardness of the material.

References

[1] Kurganova Yu A 2015 Structural metal matrix composite materials: a textbook Yu A Kurganova, A G Kolmakov. - M.: Publishing House of Bauman MSTU 141 p.
[2] Chen Yijin 2017 Metal matrix composite materials. Prospects for effective use and production (review) Metal Technology. 10 p. 25 -30.
[3] Chen Y, Qin H, Kurganova Yu A and Gaaze V K 2018 A method for introduction of Al2O3 nanofiber into aluminum alloy. IOP Conference Series: Materials Science and Engineering. 347 012050.
[4] Kurganova Yu A, Scherbakov S P 2017 Influence of discrete addition of aluminum oxide on the structure and properties of aluminum alloy. Notes of the Mining Institute. 228. p. 717-721.5.
[5] Serpova V M, Shavnev A A, Grishina O I, Krasnov E I, Solyaev U O 2014 Wettability and interfacial interaction in MCM on an aluminum matrix reinforced with Al2O3. Materials Science. 12 p.29-35.
[6] Leon C A, Mendoza-Suarez G, Drew R A L 2006 Wettability and spreading kinetics of molten aluminum on copper-coated ceramics. Journal of Material Science. 41 P.5081-5087

Chen Yijin - Postgraduate Student, Assistant, Department of Materials Science, Bauman Moscow State Technical University (National Research University), Moscow, Russia, 2597-4708, 57202284866, 0000-0001-5587-2015, N-7839-2018.
Kurganova Yuliya Anatolyevna — Doctor of Engineering Sci., Professor, Department of Materials Science, Bauman Moscow State Technical University (National Research University), Moscow, Russia, 1015-5848, 6504373743,
Scherbakov Svyatoslav Pavlovich - Assistant Professor, Department of Materials Science, Bauman Moscow State Technical University (National Research University), Moscow, Russia, 9914-0967, 55944400900.
Gaaze Vladislav Kirillovich - Master, Department of Materials Science, Bauman Moscow State Technical University (National Research University), Moscow, Russia, 57202288839.