Conference materials
UDC 52-334
DOI: https://doi.org/10.18721/JPM.153.305

Thermal and mechanical properties of a metal-matrix composite with ceramic inclusions

V. V. Rybin [1]✉, A. A. Solovyev [1], A. D. Zuev [1]

[1] Ulyanovsk State University, Ulyanovsk, Russia
✉ vlad_rib@mail.ru

Abstract. Metal-matrix composite was a blend of fine aluminum powder serving as a matrix while neodymium or aluminium oxide with 10% of volume ratio as a ceramic inclusion. Samples of the cylinder shape were manufactured used powder metallurgy method. All samples dimensions were 12.7 mm in diameter and 4 mm in height. The aim of this study was to measure the microhardness, density, porosity and thermal conductivity of the material, as well as its SEM analysis. The metallographic analysis of the composite showed a uniform distribution of ceramic inclusions with an average size of 0.8–1.2 mm and a high porosity of 5.3–5.5% in volume. The research results of the properties of aluminum composites with various oxide inclusions were compared. Their thermal properties differ significantly, while the mechanical properties vary within the same limits. The obtained values are determined by the structure of composite and its production technology. They can be used to predict of the material behavior under external influences.

Keywords: aluminium matrix composite, aluminium oxide, neodymium oxide, thermal conductivity, microhardness

Citation: Rybin V. V., Solovyev A. A., Zuev A. D., Thermal and mechanical properties of a metal-matrix composite with ceramic inclusions, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 15 (3.3) (2022) 27–30 DOI: https://doi.org/10.18721/JPM.153.305

Материалы конференции
УДК 52-334
DOI: https://doi.org/10.18721/JPM.153.305

Тепловые и механические свойства металло-матричного композита с керамическими включениями

В. В. Рыбин [1]✉, А. А. Соловьев [1], А. Д. Зуев [1]

[1] Ульяновский государственный университет, Ульяновск, Россия
✉ vlad_rib@mail.ru

Аннотация. Исследуемый в работе металло-матричный композит был подготовлен методами порошковой металлургии, состоял из алюминия и 10% по объему оксида неодима или оксида алюминия. Целью исследования было измерение микротвердости, плотности, пористости и теплопроводности материала, а также изучение его микроструктуры. Проведено сравнение полученных результатов для композитов разного состава.

Ключевые слова: композит с алюминиевой матрицей, оксид алюминия, оксид неодима, теплопроводность, микротвердость

Ссылка при цитировании: Рыбин В. В., Соловьев А. А., Зуев А. Д. Тепловые и механические свойства металло-матричного композита с керамическими включениями // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2022. Т. 15. № 3.3. С. 27–30. DOI: https://doi.org/10.18721/JPM.153.305

Introduction

Ceramic inclusions in metal-matrix composites increase their strength and hardness, chemical and thermal stability. Such materials have good resistance to elevated temperatures, therefore they are used for the production of thermal barrier coatings, turbine engines and other critical parts and assemblies.

Aluminum is a widely used matrix material due to its low weight, low cost and ease of fabrication. The reinforcing component is either oxides or carbides, and of them alumina (Al_2O_3), silicon carbide (SiC) and graphite in various configurations are widely used.

In most cases, manufacturing technology involves casting of various types and subsequent processing to give the desired geometry. Another production option is the use of powder metallurgy methods [1-2]. In this case, it is possible to obtain the required composition by simply mixing the components.

Composites used in this work based on aluminum powder with neodymium or aluminum oxide as ceramic inclusions, the volume fraction of which was 10%.

The aim of this work was to study the mechanical and thermophysical properties of the materials used.

Materials and Methods

Composites were obtained by adding Nd_2O_3 or Al_2O_3 powders at a volume ratio of 10% to Al matrix using powder metallurgy. Al powder having an average size of 30-μm as the matrix and oxide powders having an average size of 1 μm were used in the experiments.

The sintered samples were polished with various grit abrasive paper and diamond paste solution and etched also in order to conduct microstructure studies using optical microscope and scanning electron microscope (SEM). Microstructure studies were carried out using Zeiss Axio brand optical microscope, Phenom ProX brand SEM. The PMT-3M tester was used for microhardness measurements. Composite microhardness measurement method was carried out by Vickers test, which was based on ASTM standards (E. 92–82, 2003), with a Vickers hardness number

$$HV = 1.8544 \frac{P}{d^2}. \tag{1}$$

The microhardness of the produced samples was measured at room temperature for 10 s at a load of 5–20 g. After taking at least three measurements in different areas, the sample average hardness was taken.

Thermal conductivity of the composite was measured using a pulsed laser analyzer Linseis LFA 1000. Its chemical composition was determined using a micro-XRF spectrometer Bruker M4 Tornado.

Results and Discussion

The microstructure of sintered Al-Nd_2O_3 and Al-Al_2O_3 composites was characterized in order to determine if the particle distribution was consistent and the particle agglomeration occurred.

A typical microstructure of composite at high magnification is shown in Fig. 1. Locally located dark areas in the figure may be pores accumulation places and various defects in the crystal structure. The dark streaks are the result of the sample damage during the polishing process. Light areas appear to be sites of oxide accumulation.

Microstructural observations showed a homogeneous and uniform distribution of oxide particles in the composite matrix, which was noted in other researchers works [3]. The visible large light fields represent agglomerates of oxide phase particles.

The results of metallographic studies showed that the volume fraction of oxide inclusions was 2.25–2.45%, and their average size was 0.8–1.2 μm (Fig. 1). A similar structure of the composite also determined its density, which was 2.5 g/cm^3.

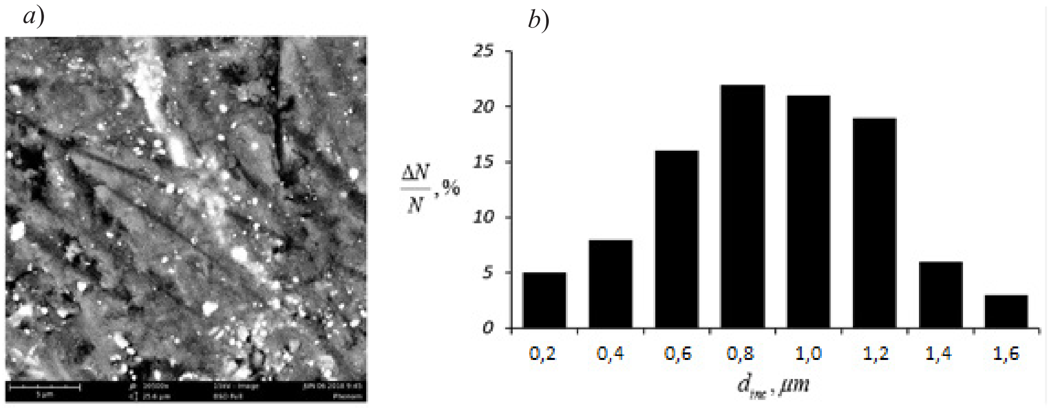

Fig. 1. SEM image (*a*) and oxide inclusions size distribution (*b*) of 10% Nd_2O_3/Al composite

The microhardness of studied composites, in comparison with cast and sintered aluminum [4], is shown in Table 1:

Table 1

Microhardness of composites and pure Al

Material	Microhardness, HV
Al+10% Nd_2O_3	54–60
Al+10% Al_2O_3	71–77
Sintered aluminum	38–42
Cast aluminum	29–31

The hardness of composites is comparable with the values obtained by other authors [5]. An increase in the hardness of the composite can be associated with a homogeneous and uniform distribution of inclusions in the aluminum matrix. Oxide particles act as a barrier to dislocation movement, strengthening the matrix by creating regions of high dislocation density. A decrease in the size of oxide particles located at the grain boundaries and distributed inside the grains causes blocking of the grain boundaries and deceleration of the movement of dislocations.

The thermal conductivity of studied composites is shown in Fig. 2.

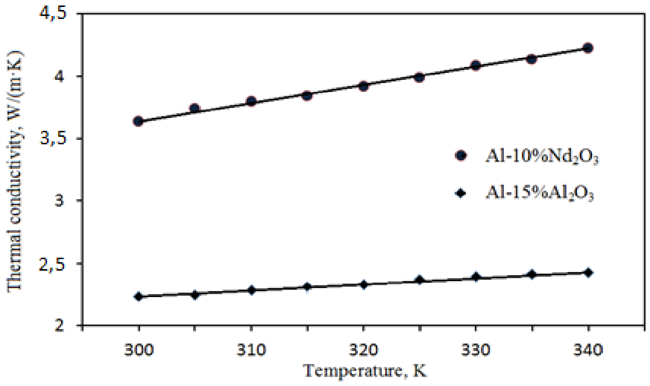

Fig. 2. The thermal conductivity of composite with inclusions of neodimium oxide and alumina

The measurement results showed that in the temperature range of 300–340 K, the materials have a thermal conductivity of 3.6–4.2 W/(m·K) for Al-Nd_2O_3 and 2.2–2.4 W/(m·K) for Al-Al_2O_3, which is significantly lower than the values for cast and sintered powder aluminum (220 and 200 W/(m·K) at room temperature, respectively [6-7]) and even aluminum oxide (37 W/(m·K) at room temperature [8]).

Such low values of the thermophysical properties of the composite indicate poor thermal contact of various phases in its structure, a large volume of internal pores with zero thermal conductivity. In addition, aluminum powder particles are easily oxidized in air and covered with a thin oxide film with low thermal conductivity. Neodymium oxide, like oxides of other rare earth elements, also has a low thermal conductivity, not exceeding 1 W/(m·K) [9].

Conclusion

Microhardness and thermal conductivity of aluminum matrix composite with neodymium and aluminum oxide inclusions were investigated. The parameter values turned out to be low and comparable to aluminum hardened by its own oxide.

The conducted studies confirm the need for a more controlled process of composite sintering under high vacuum and increased pressing pressure. The low thermal conductivity of the material under study must be taken into account when choosing the thermal modes of operation of products made from it.

REFERENCES

1. **Tosun G., Kurt M.,** The porosity, microstructure, and hardness of Al-Mg composites reinforced with micro particle SiC/Al_2O_3 produced using powder metallurgy, Composites Part B. 174 (2019) 106965.
2. **Suarsana K., Soenoko R.,** Hardness, density and porosity of Al/(SiCw+Al_2O_3p) composite by powder metallurgy process without and with sintering, Applied Mechanics and Materials. 776 (2015) 246–252.
3. **Sadeghi B., Cavaliere P., Perrone A.,** Effect of Al_2O_3, SiO_2 and carbon nanotubes on the microstructural and mechanical behavior of spark plasma sintered aluminum based nanocomposites, Particulate Science and Technology. 38 (2020) 7–14.
4. **Garbiec D., Jurczyk M., Levintant-Zayonts N., Moscickic T.,** Properties of Al–Al_2O_3 com posites synthesized by spark plasma sintering method, Archives of Civil and Mechanical Engineering. 15 (2015) 933–939.
5. **Kamaruzaman F. F., Nuruzzaman D. M., Ismail N. M., Hamedon Z., Iqbal A. K. M. A., Azhari A.,** Microstructure and properties of aluminium-aluminium oxide graded composite materials, IOP Conference Series: Materials Science and Engineering. 319 (2018) 012046.
6. **Cardarelli F.,** Materials Handbook: A Concise Desktop Reference, second ed, Springer Verlag, London, 2008.
7. **Saheb N., Khan M. S.,** Compressive strength and thermal properties of spark plasma sintered Al-Al_2O_3 nanocomposite, Science of Sintering. 50 (2018) 1–14.
8. **Gudlur P., Forness A., Lentz J., Radovic M., Muliana A.,** Thermal and mechanical properties of Al/Al_2O_3 composites at elevated temperatures, Materials Science and Engineering: A. 531 (2012) 18–27.
9. **Predeep P., Saxena N. S.,** Effective thermal conductivity and thermal diffusivity of some rare earth oxides, Physica Scripta. 55 (1997) 634–636.

THE AUTHORS

RYBIN Vladislav V.
vlad_rib@mail.ru
ORCID: 0000-0001-8280-5256

ZUEV Alexander D.
cccu.73@gmail.com
ORCID: 0000-0001-9418-4311

SOLOVYEV Alexander A.
shurken@mail.ru
ORCID: 0000-0001-7317-2813

Received 04.05.2022. Approved after reviewing 05.07.2022. Accepted 05.07.2022.