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A REVIEW ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ALUMINIUM-BASED METAL MATRIX NANOCOMPOSITES

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Abstract: *This paper provides a brief overview on the mechanical and tribological properties of aluminium-based composites reinforced with various nanoparticles. The amount of reinforcement was, most often, up to 5 % (vol. or wt.). Based on the reviewed results, it can be observed that by increasing the amount of reinforcement, properties such as hardness and density increase significantly. Tribological tests were performed mostly on pin-on-disc tribometers under dry sliding conditions. Composites reinforced with ceramic nanoparticles such as Al_2O_3, SiC, TiC, TiO_2 and TiB_2 showed a higher wear resistance than their matrix alloys. The microstructure of the nanocomposites and morphology of the worn surfaces were in most cases studied by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and energy dispersive spectroscopy (EDS).*

Keywords: *aluminium, nanoparticles, nanocomposites, hardness, wear.*

1. INTRODUCTION

Metal matrix nanocomposites (MMnC) have been of great interest to many researchers in the last two decades. These materials can have properties such as the high value of modulus, toughness, ductility and strength, making them candidates for extensive application in the automotive, aviation and other industries. Composite materials contain two or more physically distinct and mechanically separable materials [1], whereas nanocomposites have at least one component of the nano-size [2,3]. Regarding the matrix material used in the MMnC, aluminium and aluminium alloys are most often used, followed by manganese alloys and titanium alloys. Reinforcements can be classified in two ways, i.e. by the type of material (most often ceramics, i.e. various oxides, carbides, nitrides and borides) and by the shape (particles, whiskers and long fibres). Particles are usually equaxial with a spherical, cubic, tetragonal, or irregular shape, and dimensions from 10 up to 100 nm. Fibre reinforcements should have a cylindrical shape and can be short (whiskers) or continuous (long fibres). Nanoparticles are used much more than fibres.

Properties like low density, good thermal conductivity, corrosion resistance, relatively low production cost, and good recyclability have influenced a wide and significant application of aluminium and aluminium alloys as the matrix of MMnC [2,4-6].

This paper presents a brief overview of the influence of nanoparticles reinforcements on the mechanical and tribological characteristics of aluminium-based MMnC.

2. MECHANICAL PROPERTIES OF NANOCOMPOSITES WITH ALUMINIUM MATRIX

The use of Al_2O_3 reinforcement in nanocomposites with different aluminium alloy matrices showed an improvement in basic mechanical properties. In the first case [7] the matrix was an aluminium alloy AA6082 and 50 nm particles were added in 1, 2 and 3 vol. %. The SEM analysis showed that a homogeneous distribution of the reinforcements is obtained. The mechanical tests showed that with an increase in the amount of nanoparticles, the hardness and tensile strength of the nanocomposite increases, which indicates good interfacial bonding between the reinforcement and the matrix. It was found that the incorporation of 3 vol. % Al_2O_3 achieves the highest value of hardness and tensile strength. In the second case [8] the matrix was an aluminium alloy AA7075 and 20 – 30 nm particles were added in 1, 3 and 5 wt. %. Here also the highest amount of nanoparticles (5 wt. %) showed the most significant improvement of the mechanical properties. Similarly, the testing of the composite with A356 aluminium alloy matrix and a small amount of Al_2O_3 nanoparticles (0.2, 0.3 and 0.5 wt. %) in two sizes (30 and 100 nm) [9] showed the highest microhardness for the highest amount of nanoparticles.

On the other hand, Madhukar et al. [10] showed that there is an optimal value of the reinforcement amount that is not the highest used. They tested an aluminium alloy AA7150 reinforced with 0.5, 1.0, 1.5 and 2.0 wt. % SiC nanoparticles with a size of 40 – 60 nm. The lowest value of porosity and the highest values of microhardness and ultimate tensile strength were obtained for the composite with 1.5 wt. % SiC. This was coupled with the lowest value of the grain size of this composite.

Simultaneous addition of Al_2O_3 and SiC nanoparticles (with sizes of 40 and 25 – 50 nm, respectively) in the same amounts (each as 0.2, 0.5, 0.75 and 1 wt. %) to the aluminium alloy LM6 also resulted in the improvements of the microhardness and ultimate tensile strength [11]. The highest improvements were obtained for the composite with 1 wt. % Al_2O_3 and 1 wt. % SiC.

Rostami and Tajally [12] tested ANSI 332 aluminium alloy reinforced with different amounts (from 0 to 2 wt. %) of ZrO_2 and Al_2O_3 nanoparticles. The sizes of ZrO_2 and Al_2O_3 particles were 30 and 35 nm, respectively. The highest value of tensile strength was obtained for the composite with 1.25 wt. % ZrO_2 and 0.75 wt. % Al_2O_3. This can be explained by the relatively high amount of ZrO_2 which played an exceptional role in improving the microstructure of the composite. The main advantages of Al_2O_3 were its high hardness and wear resistance, so the maximum value of hardness was obtained for the maximum values of Al_2O_3, i.e. for the composite with 0 wt. % ZrO_2 and 2 wt. % Al_2O_3. A similar positive influence of Al_2O_3 particles in the AA8011 aluminium alloy-based hybrid composite (reinforced with Al_2O_3 and B_4C particles) was shown by Ramakoteswararao et al. [13]. The amount of the reinforcements was 1, 1.5 and 2 wt. % and the particles sizes were < 50 nm (Al_2O_3) and < 60 nm (B_4C).

The effect of the size (micro and nano) of the reinforcement was analysed by Kumar and Pun [14]. They tested an Al7075 aluminium alloy matrix reinforced either with micro-size (50 μm) or with nano-size (80 nm) Al_2O_3 particles in 1.5, 3 and 4.5 wt. %. Both sizes of the particles had similar effects and the highest values of the hardness and tensile strength were obtained for the highest amounts of reinforcement regardless of its size. On the other hand, Rajmohan et al. [15] showed that the addition of 1 and 2 wt. % of CuO nanoparticles (with a size of 40 nm) to the composites already reinforced with 10 wt. % SiC microparticles (with a size of 50 μm) increase both microhardness and tensile strength. The composite matrix was pure aluminium.

3. TRIBOLOGICAL PROPERTIES OF NANOCOMPOSITES WITH ALUMINIUM MATRIX

The addition of Al_2O_3 reinforcement had a similar effect on the wear resistance of the composites tested in dry sliding conditions as it had on mechanical properties, i.e. higher amount of reinforcement induced lower wear [8,11]. A similar influence is observed for the tests performed in lubricated sliding conditions [9]. In addition, it was shown that larger nanoparticles (with a size of 100 nm) give better wear resistance than smaller nanoparticles (with a size of 30 nm).

Ekka et al. [16] compared the influence of SiC and Al_2O_3 nanoparticles. Both reinforcements were added separately as 0.5, 1 and 1.5 wt. % to the aluminium alloy 7075 matrix. The sizes of the nanoparticles were from 40 to 45 nm and the wear test was in dry sliding conditions. The results show that the higher addition of SiC nanoparticles has a more favourable influence on the wear resistance, which is attributed to a better interfacial connection between SiC particles and the matrix alloy.

Following the increase in mechanical properties with the increase of nanoreinforcement amount, wear resistance in dry sliding conditions also increases. Sharifi and Karimzadeh [17] tested pure aluminium reinforced with 5, 10 and 15 wt. % Al_2O_3–AlB_{12} mixed particles (with a size of 50 – 120 nm). They found out that the wear resistance increases with the increase in the reinforcement content and that composites reinforced with 15 wt. % particles had the lowest wear. Similarly, Lekatou et al. [18] used WC and TiC nanoparticles as reinforcements, with a size of 200 – 400 nm and 400 – 700 nm, respectively. The matrix was an aluminium alloy Al1050, while the amounts of reinforcements were 0.7 and 1 vol. % TiC and 0.5 and 1.0 vol. % WC. They also showed that a higher amount of nanoreinforcement gives lower wear and that WC particles had a higher impact than TiC particles.

The effect of the size (micro and nano) of the reinforcement was analysed by Kumar et al. [19]. They tested an Al7075 aluminium alloy matrix reinforced either with micro-size (50 µm) or nano-size (80 nm) Al_2O_3 particles in 1.5, 3 and 4.5 wt. %. The results showed that composites reinforced with nanoparticles had lower wear, which was attributed to the more uniform distribution of reinforcement and finer grains boundary as showed by SEM analysis.

The influence of the nanoparticles on the both coefficient of friction and wear is studied less frequently. Jeyasimman et al. [20] tested an aluminium alloy 6061 reinforced with 2 wt. % TiC, 2 wt. % Al_2O_3 and 2 wt. % TiC–Al_2O_3 nanoparticles in dry sliding conditions. The titanium carbide was with an average particle size of less than 200 nm and alumina was with an average particle size of 40 – 50 nm. It was shown that the combination of both reinforcements gives the lowest values of coefficient of friction and wear, which was slightly lower than the values obtained when only TiC was added.

4. CONCLUSIONS

The review of the literature showed that the various ceramic particles were used as the reinforcements of different aluminium alloys but all of them impacted higher mechanical and better tribological properties of the composites over their matrices.

The mechanical properties usually depend on the properties of the reinforcing material such as type, size, morphology, and interface characteristics between the matrix and reinforcement. Comparisons of composites reinforced either with microparticles or with nanoparticles show a slight advantage of the nanocomposites.

The wear in dry sliding conditions is the main point of interest and there are only a few researches that investigate wear in lubricated sliding conditions or friction in any conditions. Reviewed studies showed that the tribological properties were correlated with the mechanical properties and that they also depend on the properties of the reinforcing material. In addition, the uniform distribution of reinforcement and finer grains boundary benefited their better tribological properties.

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REFERENCES

[1] O.E. Ogundiji, G.M. Oyatogun: Tensile and flexural properties of polyester composites reinforced by iron filings, Tribology and Materials, Vol. 1, No. 4, pp. 157-162, 2022.

[2] S. Gajević, S. Miladinović, B. Stojanović: Metallic nanocomposites: An introduction, in: H. Song, T. Nguyen, G. Yasin, N. Singh, R. Gupta (Eds.): *Nanotechnology in the Automotive Industry*, Elsevier, Amsterdam, pp. 155-161, 2022.

[3] A. Vencl, B. Stojanović, R. Gojković, S. Klančnik, Á. Czifra, K. Jakimovska, M. Harničárová: Enhancing of ZA-27 alloy wear characteristics by addition of small amount of SiC nanoparticles and its optimisation applying Taguchi method, Tribology and Materials, Vol. 1, No. 3, pp. 96-105, 2022.

[4] R.T. Mousavian, S. Behnamfard, R.A. Khosroshahi, J. Zavašnik, P. Ghosh, S. Krishnamurthy, A. Heidarzadeh, D. Brabazon: Strength-ductility trade-off via SiC nanoparticle dispersion in A356 aluminium matrix, Materials Science and Engineering A, Vol. 771, paper 138639, 2020.

[5] H. Ramezanalizadeh: Fabrication and characterization of an Al-based nanocomposite with high specific strength and good elongation using large amount CMA nanoparticles, Journal of Alloys and Compounds, Vol. 822, paper 153667, 2020.

[6] B. Stojanović, B. Tomović, S. Gajević, J. Petrović, S. Miladinović: Tribological behavior of aluminum composites using Taguchi design and ANN, Advanced Engineering Letters, Vol. 1, No. 1, pp. 28-34, 2022.

[7] V. Mohanavel, S.S. Kumar, K. Mariyappan, P. Ganeshan, T. Adithiyaa: Mechanical behavior of Al-matrix nanocomposites produced by stir casting technique, Materials Today: Proceedings, Vol. 5, No. 13, pp. 26873-26877, 2018.

[8] H.A. Al-Salihi, A.A. Mahmood, H.J. Alalkawi: Mechanical and wear behavior of AA7075 aluminum matrix composites reinforced by Al_2O_3 nanoparticles, Nanocomposites, Vol. 5, No. 3, pp. 67-73, 2019.

[9] B. Stojanović, S. Gajević, N. Kostić, S. Miladinović, A. Vencl: Optimization of parameters that affect wear of A356/Al_2O_3 nanocomposites using RSM, ANN, GA and PSO methods, Industrial Lubrication and Tribology, Vol. 74 No. 3, pp. 350-359, 2022.

[10] P. Madhukar, N. Selvaraj, C.S.P. Rao, G.V. Kumar: Enhanced performance of AA7150-SiC nanocomposites synthesized by novel fabrication process, Ceramics International, Vol. 46, No. 10, pp. 17103-17111, 2020.

[11] A.V. Muley, S. Aravindan, I.P. Singh: Mechanical and tribological studies on nano particles reinforced hybrid aluminum based composite, Manufacturing Review, Vol. 2, paper 26, 2015.

[12] R.B. Rostami, M. Tajally: Improvements in microstructure and mechanical properties of Al-Si-Cu alloy–Al_2O_3 nanocomposite modified by ZrO_2, Journal of Materials Research, Vol. 29, No. 21, pp. 2505-2513, 2014.

[13] C. Ramakoteswararao, P. Venkataramaiah, J. Venumurali: Study on fabrication and mechanical characterization of aluminium hybrid nanocomposites, Materials Today: Proceedings, Vol. 59, No. 1, pp. 568-575, 2022.

[14] S. Kumar, A.K. Pun: The effects of the size of filler materials on the mechanical properties of aluminium matrix composites, Materials Today: Proceedings, In Press, DOI: 10.1016/j.matpr.2022.12.146

[15] T. Rajmohan, K. Palanikumar, S. Arumugam: Synthesis and characterization of sintered hybrid aluminium matrix composites reinforced with nanocopper oxide particles

and microsilicon carbide particles, Composites: Part B, Vol. 59, pp. 43-49, 2014.

[16] K.K. Ekka, S.R. Chauhan, Varun: Dry sliding wear characteristics of SiC and Al_2O_3 nanoparticulate aluminium matrix composite using Taguchi technique, Arabian Journal for Science and Engineering, Vol. 40, No. 2, pp. 571-581, 2015.

[17] E.M. Sharifi, F. Karimzadeh: Wear behavior of aluminum matrix hybrid nanocomposites fabricated by powder metallurgy, Wear, Vol. 271, No. 7-8, pp. 1072-1079, 2011.

[18] A. Lekatou, A.E. Karantzalis, A. Evangelou, V. Gousia, G. Kaptay, Z. Gácsi, P. Baumli, A. Simon: Aluminium reinforced by WC and TiC nanoparticles (ex-situ) and aluminide particles (in-situ): Microstructure, wear and corrosion behaviour, Material Design, Vol. 65, pp. 1121-1135, 2015.

[19] S. Kumar, A. Kumar, A. Poddar, P. Asthana: Investigation on wear behavior of aluminium matrix micro and nanocomposites. Materials Today: Proceedings, Vol. 56, No. 5, pp. 2839-2845, 2022.

[20] D. Jeyasimman, R. Narayanasamy, R. Ponalagusamy, V. Anandakrishnan, M. Kamaraj: The effects of various reinforcements on dry sliding wear behaviour of AA 6061 nanocomposites, Materials and Design, Vol. 64, pp. 783-793, 2014.