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Tribological characteristics of Al/SiC/Gr hybrid composites

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Abstract. Metal matrix composites (MMCs) are considered as important engineering materials due to their excellent mechanical, as well as tribological properties. When the metal (or alloy) matrix is reinforced with two or more reinforcements, those composites are the so-called hybrid composites. The aluminum metal matrix composites, reinforced with silicon carbide (SiC) and graphite (Gr), are extensively used due to their high strength and wear resistance. The tribological characteristics of such materials are superior to characteristics of the matrix. This research is presenting influence of the load and the graphite and silicon carbide contents the composites' wear rate and the friction coefficient.

1 Introduction

Composite materials consist of the matrix, content of which is much greater with respect to other materials, and the reinforcer(s), i.e. material(s) whose properties result in desired properties of the composite. Materials that can be used for the substrate, i.e. the matrix of composites, can be metals, polymers and ceramic materials. If the composite matrix is a metal, then one speaks about the metal matrix composites (MMC); if the matrix is made of the polymer material, then such composites are the so-called polymer matrix composites (PMC); the composites whose matrix is a ceramic material are the ceramic matrix composites (CMC). Metal matrix composites (MMCs) are the materials with the superior properties with respect to the conventional materials [1].

Because of the raising necessity for producing materials with better characteristics, than the existing ones, the investigation of the MMCs is increased in last decades. Usually, reinforcements of the MMCs are ceramics, which can be in form of particles, whiskers or fibers. When two or more different reinforcements are incorporated in the metal matrix the new type of the MMC is developed, called the hybrid metal matrix composite (HMMCs). [2, 3].

Characteristics of hybrid composites depend on properties of their reinforcements (e.g. their hardness, size of particles, volume fractions), distribution of the reinforcing phases, as well as the manufacturing technique. Development of the hybrid MMCs is performed so

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that their performances would be better than those of the conventional MMCs [2, 4]. The high resistance-to-weight and strength-to-weight ratios, hardness and wear resistance, good creep behavior, small weight, design flexibility and other good characteristics are the reason why the HMMCs' application is rapidly growing [5-7].

The most used MMCs are the aluminum matrix composites (AMCs). The fact that aluminum and its alloys have low specific (volume) weight, high corrosion resistance and easy processing, is the reason for aluminum to be widely used in industry, in general [4, 8].

Compared to conventional alloys, the AMCs provide many advantages, such as: high strength, superior high temperature properties, low density, better stiffness, good damping characteristics, abrasion and wear resistance [8, 9].

2 Types of reinforcements

Characteristics of composites are determined by: type of reinforcement, particle sizes of reinforcements and volume fractions of reinforcements, microstructure, homogeneity and isotropy of the system.

As reinforcements in aluminum matrix composites (AMCs) usually are used graphite (Gr), silicon carbide (SiC), titanium carbide (TiC), titanium diboride (TiB_2), alumina (Al_2O_3), tungsten carbide (WC), boron carbide (B_4C), fly ash, zircon (Zr), silicon nitride (Si_3N_4) and some organic wastes such as the rice husk ash, coconut shell ash, palm oil fuel ash and the sugar cane bagasse. With addition of hard reinforcements (silicon carbide, alumina, titanium carbide), with respect to the matrix alloy, the hardness, strength and wear resistance of the composites are improved [10, 11].

Compared to conventional alloys, the SiC particle reinforced AMCs have higher mechanical strength and wear resistance, due to the fact that SiC particles have high modulus of elasticity and yield strength, and the base alloy has the low yield strength and good plasticity [4, 10]. Because of those characteristics, in machining of the composites, matrix deforms plastically and the SiC particles only deform elastically or break. For the better tribological characteristics of aluminum matrix composites, as a reinforcements, commonly are used both SiC and Gr [12, 13].

By combining these two reinforcements with aluminum matrix the hybrid composites are develop. Those hybrid composites are known as the Al/SiC/Gr hybrid composites.

3 Manufacturing methods

Manufacturing process has a big effect on tribological properties of the Al/SiC/Gr composite materials. Microstructure, distribution of reinforcement particles and bonds between the matrix and the reinforcement are influenced by the fabrication process. It can cause porosity formation, poor wettability and improper distribution of reinforcement.

At the industrial level, there are two groups of basic processes for fabrication of the aluminum matrix composites: processing in the solid state and processing in the liquid state.

The solid state fabrication of Metal Matrix Composites is a process, in which the MMCs are formed due to bonding of the matrix metal and the dispersed reinforcement phase, which is a result of the mutual diffusion the in solid state, at elevated temperature and under pressure. The fabrication processes in the solid state include the powder metallurgy technology, diffusion metallization and the vapor deposition technology. Sintering fabrication of the Metal Matrix Composites is a process, in which a powder of a matrix metal is mixed with a powder of the dispersed phase (in the form of particles or short fibers), followed by compacting and sintering in the solid state (sometimes with presence of a liquid).

The liquid state fabrication of Metal Matrix Composites is a process where the dispersed reinforcement phase is incorporated into the molten matrix metal, what is followed by solidification. Fabrication processes in the liquid state include stir-casting, compo-casting, squeeze casting, spray casting and reactive – in situ process.

Selection of the fabrication process depends on numerous factors, like the type and level of reinforcement load, desired degree of micro-structural integrity etc. [14-16].

Based on review of literature on HMMCs, it was noticed that the beginning of the Al/SiC/Gr hybrid composites research points to application of the higher weight/mass % share of SiC particles, as compared to research results of the same composites of the more recent times. The higher %/mass share of the SiC particles leads to more difficult manufacturing and processing of the material, since increased content of the ceramic particles causes increase of the composite's hardness. In the last few years, research of these composites shows that the content of the SiC particles did not exceed 10 wt %, while the minimum content was 3% of SiC particles, what improves the manufacturing and machining of the Al base hybrid composites, without compromising their mechanical properties.

Researchers have also studied tribological behavior of the Al/SiC/Gr composites, by application of the statistical methods with smaller number of experiments like the Taguchi method, the Analysis of Variance (ANOVA), the Full Factorial Method, Response Surface Methodology, Center Composite Design, Taguchi Grey Analysis and Artificial Neural Network.

4 Influence of the load and reinforcement content on composites' tribological properties

Infiltration of the reinforcement particles into the metal matrix affects the tribological and mechanical properties of the composite materials. Depending on various requirements of the industry, the volume shares percentages of SiC and Gr are being combined, as well as sizes of the reinforcing particles.

Generally, the friction and wear properties of composites also depend on the shape and distribution of hard or soft particles filled in the matrix. Hard particles increase the strength and wear resistance of composites, but decrease their ductility, whereas the soft particles acting as lubricant decrease the coefficient of friction [17, 18].

Tribological behavior of specimens made of the Al/SiC/Gr composites were studied by conducting the dry sliding wear test, mainly on the pin-on- disc tribometer. The wear test parameters were within the following intervals: load between 10 N to 60 N, sliding speed from 1 m/s to 3 m/s, the sliding distance up to 1000 m. The size of the reinforcement particles varied from nm for SiC to mm for Gr.

The effect of load on the wear rate of the Al/SiC/Gr composites, with different weight percentage of SiC particles, in the presence of graphite, is shown in Figure 1.

Based on the diagram in Figure 1, one can conclude that the wear rate increases with the load increase. Increase of the SiC reinforcing particles volume share in the hybrid composite, on the other hand, causes reducing of the wear rate, since the hardness of the composite material is increased. The sliding speed increase, for the same experimental conditions (the same load and the sliding distance), causes decrease of the wear rate.

The effect of the load on coefficient of friction of the Al/SiC/Gr composites, with different weight percentage of SiC particles, in the presence of graphite, is shown in Figure 2.

In addition, the effect of load on coefficient of friction of the Al/SiC/Gr composites with different weight percentage of Gr particles and fixed 5 wt % SiC is shown Figure 3.

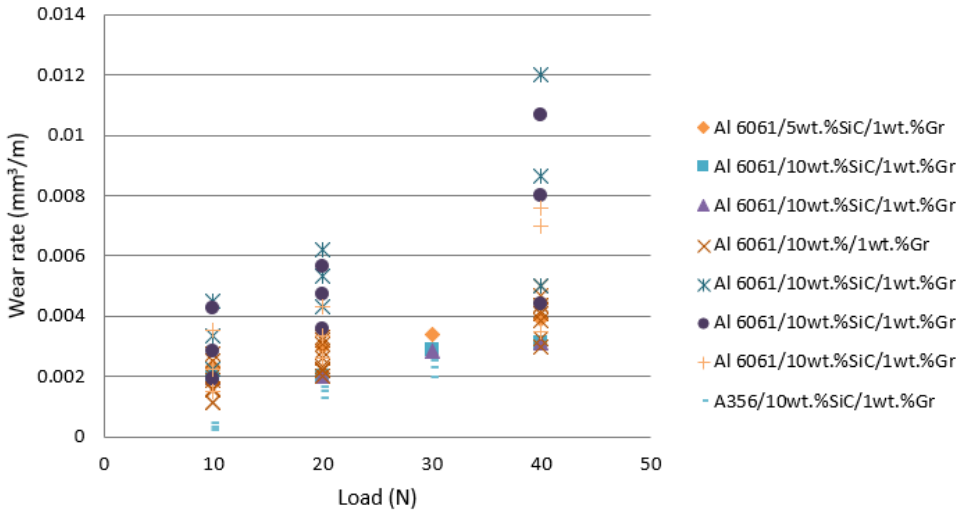

Fig. 1. The effect of load on the wear rate of the Al/SiC/Gr composites with different wt % of the SiC particles and fixed 1 wt % Gr [13, 19-20].

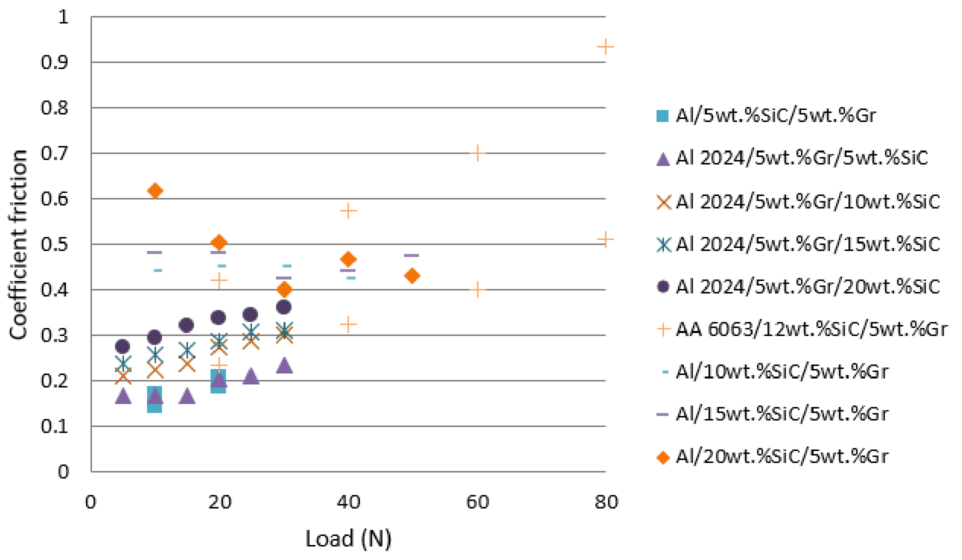

Fig. 2. The effect of load on coefficient of friction of the Al/SiC/Gr composites with different weight percentage of SiC particles and fixed 5 wt % Gr [21-24].

From diagram in Figure 2, one can notice that the friction coefficient increases with the load increase, as well as with the SiC particles volume share increase. The sliding distance has the same effect, as well, while the sliding speed increase causes decrease of the friction coefficient of the composite material.

From diagram in Figure 3 one can notice that the coefficient of friction increases with increase of the load, as well as that the sliding distance increase cause increase of the coefficient of friction. It can also be concluded that the friction coefficient increases with increase of the Gr reinforcing particles.

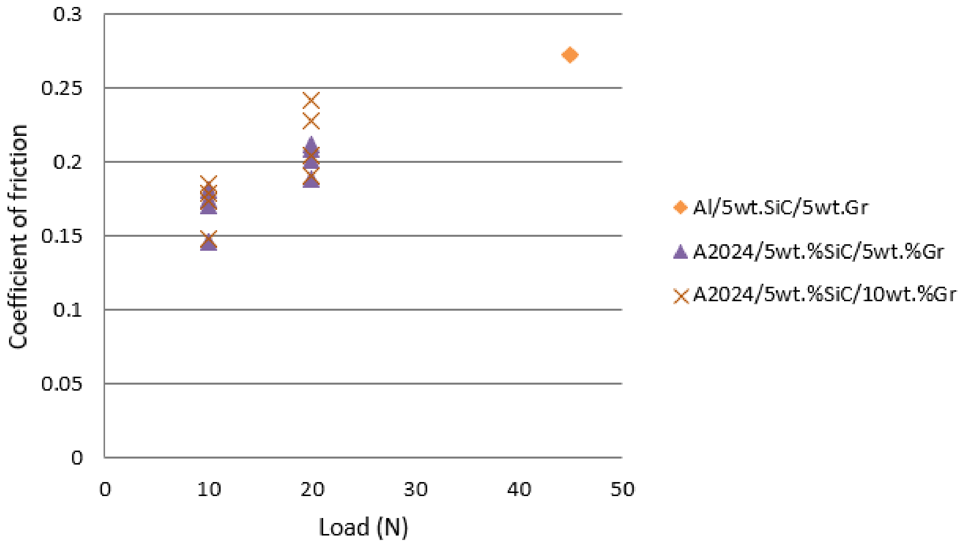

Fig. 3. The effect of load on coefficient of friction of the Al/SiC/Gr composites with different wt % of the Gr particles and fixed 5 wt % SiC [15, 25].

5 Conclusions

Though the composite materials were known for a long time and were used for thousands of years, their research is intensified and well invested in only in recent times.

Improvement of properties of the Al/SiC/Gr hybrid metal matrix composites (HMMCs) is strongly dependent on the nature of the reinforcement, its hardness, particles sizes, volume share and uniformity of dispersion within the matrix and the method of hybrid production.

The quality of the hybrid metal matrix composites (HMMCs) can also be improved by the manufacturing process itself, with the proper choice of the production parameters (the pouring temperature, stirring speed, preheating temperature of reinforcement etc.).

The hybrid composites generally have better tribological properties than the conventional composites.

Adding of the hard reinforcer – ceramic materials (SiC) – causes increase of composite's mechanical and tribological properties with respect to the same properties of the base aluminum alloy (hardness, tensile strength, toughness, wear resistance and corrosion resistance).

Adding the second, soft reinforcer – graphite (Gr) – causes decrease of the friction coefficient and improves the machinability of the hybrid composites.

Thus, one can conclude that the adequate combination of the manufacturing process, reinforcement material, its content and size of its particles, can result in optimal tribological properties of the aluminum based hybrid composites that are much better than properties of the conventional composites.

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References

1. B. Stojanovic, S. Milojevic, *Characterization, Manufacturing and Application of Metal Matrix* Composites*/Advances in Materials Science Research* (Nova Science Publishers, Ed. Maryann C. Wythers, New York, 2017)
2. A. Zeren, Ind. Lubr. Trib., **67**(3), 262 (2015)
3. S.O. Adeosun, L.O. Osoba, O.O. Taiwo, Int. J. Chem. Mol. Nucl. Mats. Metall. Eng., **8**(7), 731 (2014)
4. S. Basavarajappa, J.P. Davim, Mater. Res., **16**(5), 990 (2013)
5. G. Dixit, M.M. Khan, Jordan J. Mech. Ind. Eng., **8**(6), 7 (2014)
6. B. Stojanovic, L. Ivanović, Tech. Gazz., **22**(1), 247 (2015)
7. B. Stojanovic, J. Glisovic, J. 2016. *Automotive Engine Materials. In: Saleem Hashmi (ed.) Reference Module in Materials Science and Materials Engineering* (Elsevier, Oxford, 2016)
8. S. Bansal, J. S. Saini, Def. Sci. J., **65**(4), 330 (2015)
9. P. Suresh, K. Marimuthu, S. Ranganathan, Austral. J. Bas. Appl. Sci., **7**(9), 341 (2013)
10. M. Naveed, A. R. Anwar Khan, Int. J. Sci. Res., **4**(9), 146 (2015)
11. L. Lancaster, M.H. Lung, D. Sujan, World Acad. Sci. Eng. Techn., **73,** 1136 (2013)
12. P. Suresh, K. Marimuthu, S. Ranganathan, G. Arunkumar, Int. J. Adv. Eng. Appl., **6**(3), 38 (2013)
13. M. Zakaulla, A.R. Anwar Khan, World Acad. Sci., Eng. Techn. Int. J. Envir. Chem. Ecol. Geol. Geoph. Eng., **9**(6), 697 (2015)
14. B. Stojanovic, *Tribological behavior of hybrid composites with the A356 matrix*, *PhD Dissertation, Faculty of Engineering* (University of Kragujevac, Serbia, 2013)
15. S. Suresha, B.K. Sridhara, Mat. Des., **34,** 576 (2012)
16. P. Ravindran, K. Manisekar, P. Rathika, P. Narayanasamy, Mat. Des., **45,** 561 (2013)
17. A. Vencl, I. Bobic, S. Arostegui, B. Bobic, A. Marinkovic, M. Babic, J. All. Comp., **506,** 631 (2010)
18. N. Radhika, R. Subramanian, S. Venkat Prasat, B. Anandavel, Ind. Lub. Trib., **64**(6), 359 (2012)
19. S. Şahın, N. Yüksel, H. Durmuş, S.G. İrızalp, Mat. Techn., **48**(5), 639 (2014)
20. B. Stojanovic, J. Blagojevic, M. Babic, S. Velickovic, S. Miladinovic, Ind. Lub. Trib., **69**(6), 1005 (2017)
21. B. Pavithran, J. Swathanandan, Int. J. Techn. Enhan. Emerg. Eng. Res., **3**(04), 60 (2015)
22. A.N. Varghese, P.V. Pradeep, Int. J. Theor. Appl. Res. Mech. Engin., **3**(3), 2319 (2014)
23. B. Stojanovic, M. Babic, S. Veličković, J. Blagojević, Tribol. Trans., **59**(3), 522 (2016)
24. S. Veličković, S. Miladinović, B. Stojanović, R. R. Nikolić, B. Hadzima, D. Arsić, Production Engineering Archives, **14**, (2018).
25. P. Ravindran, K. Manisekar, P. Narayanasamy, N. Selvakumar, R. Narayanasamy, Mat. Des., **39,** 42 (2012)