TRIBOLOGICAL CHARACTERISTICS OF ALUMINIUM HYBRID COMPOSITES REINFORCED WITH SILICON CARBIDE AND GRAPHITE. A REVIEW

B. STOJANOVIC[a*], M. BABIC[a], S. MITROVIC[a], A. VENCL[b], N. MILORADOVIC[a], M. PANTIC[a]

[a] *Faculty of Engineering, University of Kragujevac, 6 Sestre Janjic Street, 34 000 Kragujevac, Serbia*
E-mail: *blaza@kg.ac.rs*
[b] *Faculty of Mechanical Engineering, University of Belgrade, 11 000 Belgrade, Serbia*

ABSTRACT

This paper presents tribological characteristics of hybrid composites with aluminium matrix, reinforced with silicon carbide (SiC) and graphite (Gr). Newly formed Al/SiC/Gr hybrid composites are the combination of the two different hybrid materials. Namely, hard particles of silicon carbide increase the hardness and resistance to wear, while soft particles of graphite improve lubrication and reduce friction coefficient and wear. It is possible to obtain Al/SiC/Gr hybrid composites by different methods of casting. Tribological tests show that load, sliding speed, sliding distance, content and size of reinforcement particles influence the size and the type of wear and friction coefficient of Al/SiC/Gr hybrid composites with aluminium matrix.

Keywords: tribology, hybrid composites, aluminium, metal matrix composites (MMC), wear, coefficient of friction, SiC, graphite.

AIMS AND BACKGROUND

Composite materials (composites) are formed by mixing of two or more materials or phases of the same material. The composite has completely new, different and better characteristics in comparison to its constituents. The components do not blend with each other or do not get dissolved, so there is a visible difference between them.

* For correspondence.

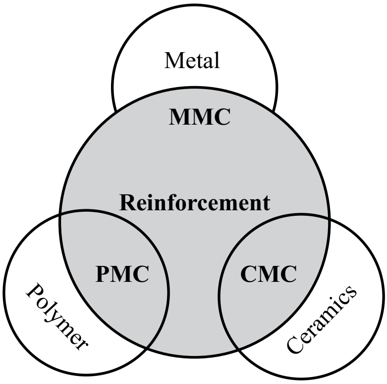

Fig. 1. Types of composites

Essentially, the composites consist of the base (the matrix), which content is much higher in comparison to other materials, and reinforcement, i.e. material with which the desired properties of composites are achieved. The base or the matrix may be metal, polymer and ceramic (Fig. 1). When the matrix is metal, the composites are metal matrix composites (MMC), when the matrix is polymer, the composites are polymer matrix composites (PMC) and when the matrix is ceramic, the composites are ceramic matrix composites (CMC).

When talking about metal matrix composites, the aluminium and its alloys are mostly used as a base. Aluminium and its alloys can accept various reinforcements and improvers. Aluminium composites have a number of positive features such as: small density, good thermal conductivity and resistance to corrosion. However, aluminium alloys also have certain defects in the form of higher coefficient of thermal expansion and inadequate tribological characteristics. Increase of stiffness, hardness, resistance to fatigue, as well as the improvement of tribological characteristics are achieved by adding appropriate reinforcements and improvers and by forming aluminium composites. Commonly used reinforcements are SiC, Al_2O_3 and graphite[1–7].

The influence of SiC, Al_2O_3 and graphite on tribological and mechanical characteristics is different. By increase of mass or volumetric share of SiC, Al_2O_3 and graphite, tribological characteristics of composites are changed. By combining the appropriate share of these two materials, the optimum values of tribological and mechanical characteristics of materials are achieved.

The composites reinforced with SiC (silicon carbide) and graphite (Gr) are called Al/SiC/Gr hybrid composites.

A small number of scientists was engaged in research of tribological and mechanical characteristics of hybrid Al/SiC/Gr composites. The research review is given below.

Ted Guo and associates[8] have studied tribological behaviour of Al/SiC/Gr composites with 10% SiC and different content of graphite (2, 5 and 8%). With increase of graphite content up to 5%, the value of friction coefficient decreases due to forming of lubricating layer (Fig. 2). Further increase of graphite content does not have significant effect on friction coefficient, except that composite hardness decreases.

Guo and Tsao[8] used aluminium 6061 (average powder size: 30 μm) as a base and SiC (average powder size: 45 μm) and graphite (average powder size: 8 μm) as reinforcements. SiC percentage is 10% of volumetric content and percentage of graphite varies between 2, 5 and 8% of volumetric share (v/o). Hybrid composites of appropriate composition were obtained using semi-solid powder densification method on the 10t Instron device (model 1125).

Testing of tribological characteristics was performed on tribometer during period of 5 min, without lubrication, at pressure of 0.094 MPa and at sliding speed of 1.09 m/s. The measurements showed that friction coefficient decreases with increase of graphite content (for 0 to 5% Gr) and after that friction coefficient has constant value (for 5 to 8% Gr). Measuring of counter-body worn material was done alongside with hybrid composite A356 with the same content of graphite. Unlike A356 composite where mass dissipation or wear increases with increase of graphite content, with composites having Al6061 base the wear increases up to 5% Gr and then decreases (Fig. 3).

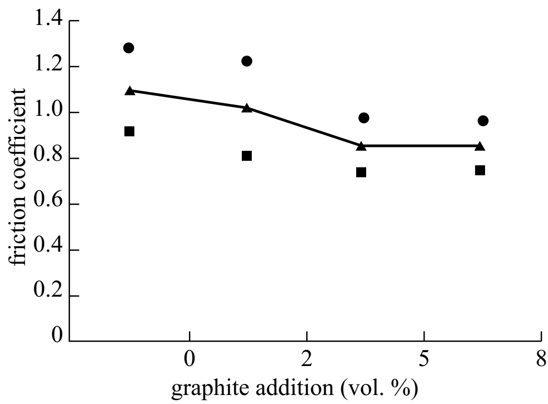

Fig. 2. Change of friction coefficient depending on content of graphite[8]

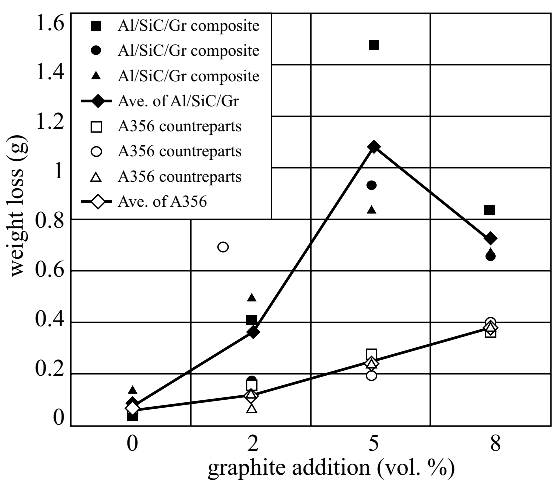

Fig. 3. Wear of composite and counter-body depending on content of graphite[8]

Riahi and Alpas[9] focused on systemic tests of the role of tribo-layers which are formed on contact surfaces of hybrid composites with A356 aluminium base. Tests were done on Al/SiC/Gr hybrid composite with A356 base, 10% SiC with particle size of 16 μm and 3% of graphite with particle size of 80 μm and 138 μm.

Performed tribological tests determined dependence between wear and sliding speed and load. The tests were performed on block on ring tribometer for loads of 5–420 N and for sliding speeds of 0.2–3.0 m/s (Fig. 4).

Basavarajappa et al.[10–12] studied the tribological behaviour of hybrid composites with Al2219 aluminum base reinforced with silicon–carbide and graphite. Hybrid composites were obtained by liquid metallurgy process.

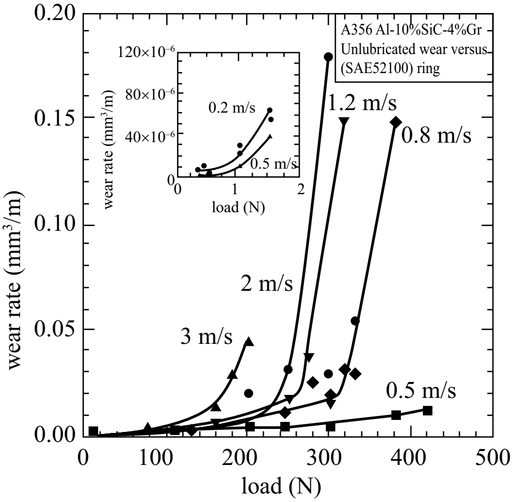

Fig. 4. Dependence of Al/SiC/Gr composite wear on load and sliding speed[9]

RESULTS AND DISCUSSION

A small number of scientists were engaged in research of tribological and mechanical characteristics of hybrid Al/SiC/Gr composites. The research review is given below.

Testing of tribological characteristics was performed according to ASTM G99-95 standard on a pin-on-disc tribometer. Four different materials were tested: Al2219, Al2219/5SiC/3Gr, Al2219/10SiC/3Gr and Al2219/15SiC/3Gr. With tested composites, SiC and graphite of volumetric share of 3% with particles size of 45 μm were used as reinforcements. The percentage of SiC in tested samples varied between 5, 10 and 15% of volumetric share with particle size of 25 μm.

Tribological tests are performed for loads ranging from 10 to 60 N and sliding speeds of 1.53, 3.0, 4.6 and 6.1 m/s. The tests are performed on a sliding distance of 5000 m and the material of disc is EN 36 steel with hardness of 65 HRc.

Tests results (Refs 10–12) show that with increase of SiC percentage share, the resistance to composite wear increases, that is, wear decreases (Fig. 5).

With increase of sliding distance wear increases, and it decreases with increase of SiC percentage (Fig. 6).

The wear increases with increase of sliding speed and load, especially above 4.6 m/s and 50 N (Figs 7 and 8). At lower sliding speeds, the main wear mechanism is abrasive wear, while, at higher speeds, the conclusion can not be drawn due to delamination[10–12].

Indian scientists Suresha and Sridhara[13–16] have studied tribological behaviour of aluminium hybrid composites with addition of SiC and graphite or the so-called Al/SiC/Gr composites. They have studied dependence between wear and percentage content of reinforcements, the first, the other or both.

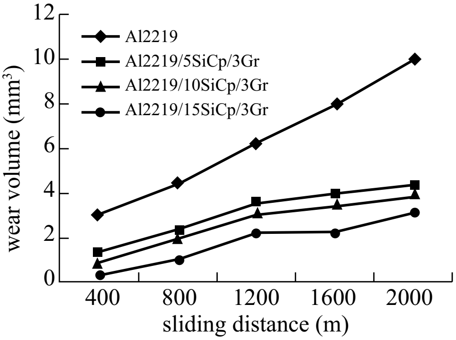

Fig. 5. Wear dependence on sliding distance[10–12]

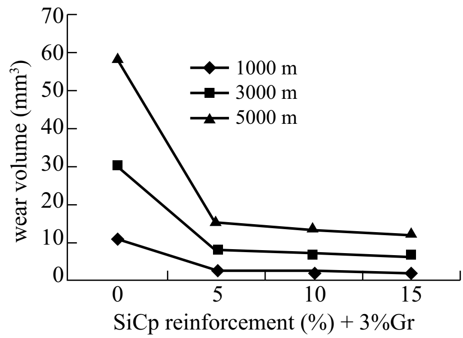

Fig. 6. Wear dependence on graphite content for different sliding distances[10–12]

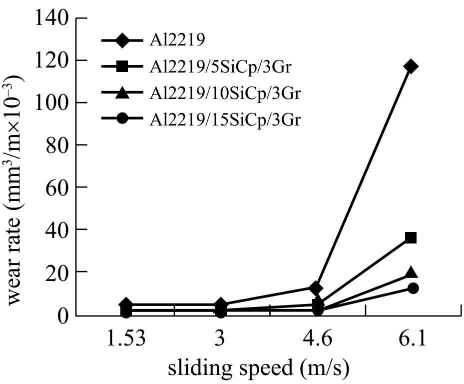

Fig. 7. Wear dependence of sliding speed[10–12]

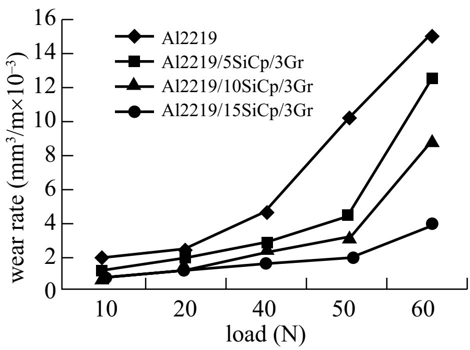

Fig. 8. Dependence between wear and load for sliding speed of 3 m/s and sliding distance of 5000 m[13–15]

Hybrid composites are obtained with stir casting procedure. Aluminium alloy LM25 (AL–Si7Mg0.5) is used as matrix. Overall percentage of reinforcements in hybrid composites is 10% of volumetric share, while the individual percentage of both reinforcements varies from 0, 1.25, 2.5, 3.75 up to 5.0% of volumetric share. Particle size of SiC is 10–20 μm, density is 3.22 g/cm^3, and particle size of graphite is 70–80 μm and density 2.09–2.23 g/cm^3.

Tribological tests were performed on tribometer with a pin-on-disc contact pair, according to ASTM G99'95a standard, without lubrication, for loads of 15–75 N, sliding distance of 400–2000 m, sliding speed of 0.4–2.0 m/s, with equal percentage content of SiC and Gr in hybrid composite. The EN 31 steel having surface roughness $R_a = 0.1$ μm is used as disc material. Percentage of reinforcements, sliding speeds, loads and sliding distances (Fig. 9) have influence on wear of Al/SiC/Gr composite.

Increase of graphite percentage content in a composite leads to decrease of wear due to forming of lubricant layer. On the other hand, addition of SiC im-

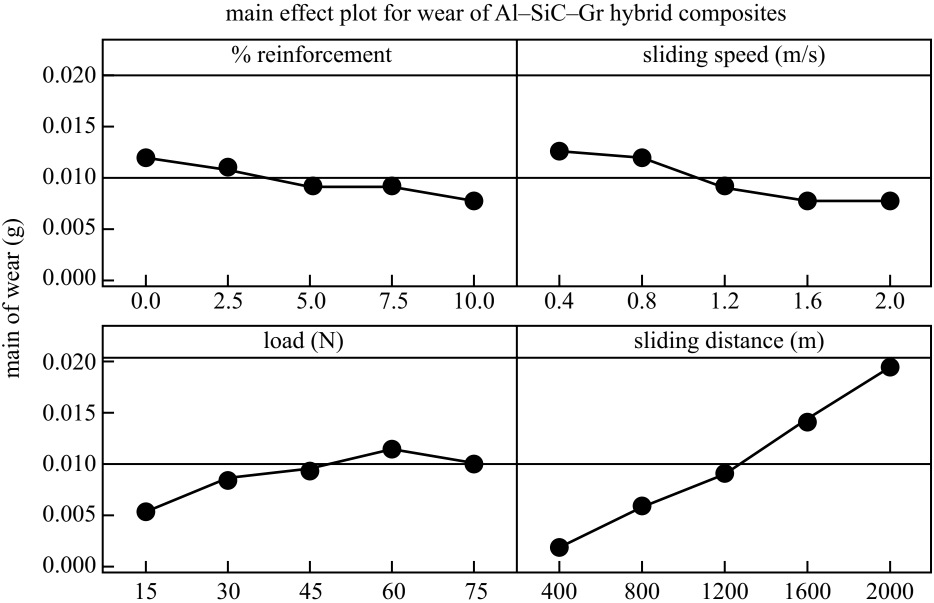

Fig. 9. Dependence between wear and reinforcement content, sliding speed and sliding distance for Al/SiC/Gr hybrid composites[13]

proves strength and resistance to wear of composite, but reduces machinability of parts and increases stiffness. Combined use of the both reinforcements leads to improvement both of tribological and mechanical characteristics of aluminium alloys. Optimum percentage of reinforcements is 7.5% regardless of the load, sliding speed and sliding distance.

Leng and associates[17,18] have studied the influence of graphite particle size on tribological and mechanical characteristics of hybrid composites. Aluminium Al2024 makes the base of the composite, and SiC with percentage share of 40% and particle size of 3 μm is used as reinforcement. Graphite with volume content of 5% is used as other reinforcement, but with different particle sizes of 1, 6 and 20 μm. Hybrid Al/SiC/Gr composites are obtained with Squeeze casting method.

Mechanical characteristics (tensile strength and elastic modulus) are determined for each of these composites. Tensile strength and elastic modulus of obtained hybrid composites decrease with increase of graphite particle size.

Tests of tribological characteristics were performed on a tribometer working on block-on-ring principle. The rings are made of composites and blocks are made of W18Cr4V steel. Tests are realised under load of 150 N, sliding speed of 0.4 m/s, during time period of 120 s, at temperature of 22±3°C and without lubrication.

The measured values of friction coefficient for Al/SiC composites are within boundaries of 0.3÷0.5. Friction coefficient of Al/SiC/Gr hybrid composites is within boundaries of 0.25÷0.3. These values are much smaller due to the lubricating properties of the graphite and there is obvious smaller dissipation of values.

The measuring of mass of worn material is performed within tribological tests. The wear of Al/SiC (484.0 mg) composite is the highest, while the wear of hybrid composites is much lower (1.4÷2.7 mg). Material losses with hybrid composites are 170 to 340 times smaller than with Al/SiC composites (Fig. 10). When referring to graphite particle size, the lowest wear is found with composites with the largest particles (20 μm), and the highest wear is found with composites with the smallest particles (1 μm).

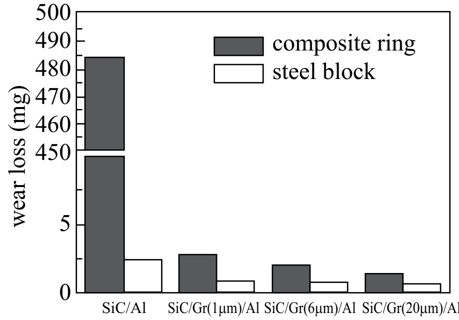

Fig. 10. Wear of hybrid composites and counter bodies with different particle sizes of graphite[17]

By adding graphite, the friction coefficient of hybrid composites decreases and resistance to wear considerably increases. Besides, wear of counter body is reduced by 60–70%.

Wear resistance of Al/SiC/Gr hybrid composites increases with the increase of particle size of graphite. Improvement of tribological characteristics occurs with improving of lubrication of tribo-layers which consist of a mixture of iron oxide, graphite, SiC and aluminium particles.

Mahdavi and Akhlaghi[19,20] have studied tribological behaviour of Al/SiC/Gr hybrid composites obtained by a new method – *in situ* powder metallurgy (IPM). Hybrid composites with aluminium base reinforced by silicon–carbide and graphite represent unique class of the advanced materials developed to be used in tribological applications. The base of Al/SiC/Gr hybrid composites is Al6061. Obtained composites contain 9% of graphite and percentage content of SiC varies within 0÷40%. Average particle size of SiC is 19 μm and of graphite particle – 75 μm. Density of SiC is 3.2 g/cm^3, and density of graphite – 2.2 g/cm^3.

Tribological tests are performed on a tribometer with a pin-on-disc contact. Sliding distances are 250, 500, 750 and 1000 m. Pin material is steel (1.5Cr, 1C, 0.35Mn, 0.25Si) of 64 HRc hardness. Load is 20 N, pressure – 1 MPa and sliding speed – 0.5 m/s.

Hardness of obtained samples increases with the increase of SiC content. When referring to tribological characteristics, wear intensity increases with increase of sliding distance. However, when referring to the SiC percentage, the wear decreases with the increase of SiC content up to 20%, then, for 20–40% SiC, the wear increases again (Fig. 11). Regarding the friction coefficient, its value decreases with the increase of SiC content and it has the smallest value for 30%

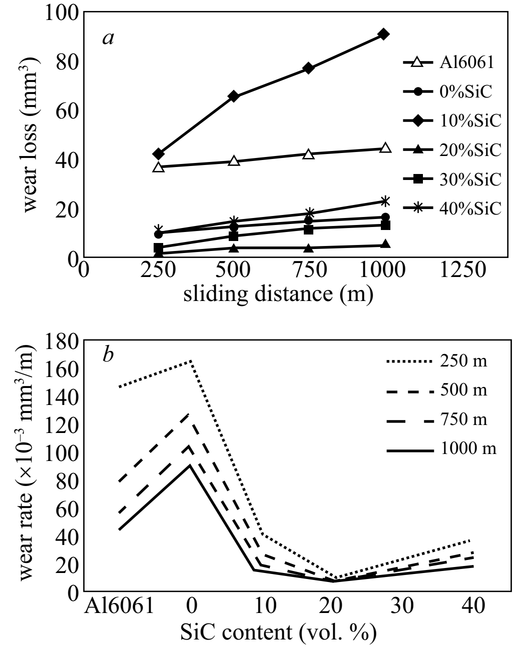

Fig. 11. Dependence between wear intensity and sliding distance (*a*) and content of SiC in Al/SiC/Gr hybrid composites with 9% of graphite (*b*) (Ref. 19)

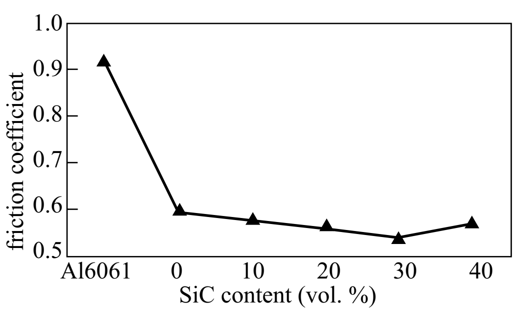

Fig. 12. Dependence between friction coefficient and SiC content in Al/SiC/Gr hybrid composites with 9% of graphite[19]

of SiC. After that, the friction coefficient increases (Fig. 12).

The same authors[21] analysed Al/SiC/Gr hybrid composite with Al6061base, with percentage share of 30% of SiC and variable content of graphite from 0 to 13%, obtained by *in situ* IPM procedure. Tribological tests are performed on a tribometer with a pin-on-disc contact. The particle size of SiC is 93 μm and particle size of graphite is 75 μm. Test conditions, i.e. load, sliding speed and sliding distance are the same as in Ref. 19.

Tribological tests results for Al–Gr composites show that wear intensity increases with the increase of sliding distance and with increase in graphite content (Fig. 13). The same trend exists also with Al/SiC/Gr composites, except that wear intensity is much lower. The lowest wear with Al/SiC/Gr composites appears when the graphite content is 9%. With Al/30SiC/9Gr hybrid composites the wear is 15÷30 times lower than with Al/9Gr composites (Fig. 14).

Increase of graphite content in composites leads to decrease of friction coefficient. The values of friction coefficient with Al/SiC/Gr hybrid composites are lower by 20% than with Al/Gr composites (Fig. 15).

In Ref. 22 is investigated the influence of SiC particle size on tribological characteristics of Al–SiC–Gr hybrid composites. Hybrid composites with A6061 base, reinforced by 10% of SiC and 0÷5% of graphite, are obtained by IPM procedure. Sizes of SiC particles are 19, 93 and 146 μm and density – 3.2 g/cm^3, while particle size of graphite – 75 μm and density – 2.2 g/cm^3.

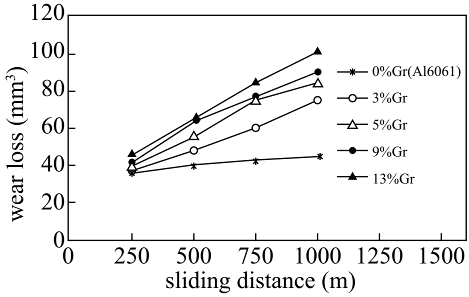

Fig. 13. Dependence between hybrid composites wear loss and sliding distance for different values of graphite content[21]

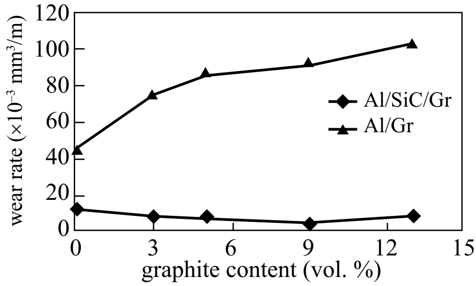

Fig. 14. Dependence between hybrid composites wear rate and graphite content[21]

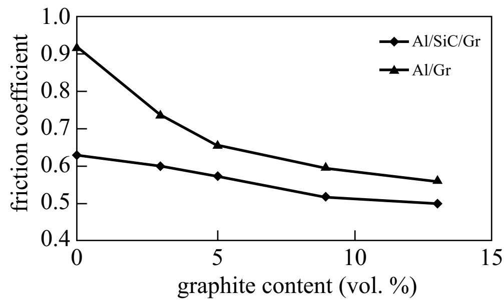

Fig. 15. Dependence between hybrid composites friction coefficient and graphite content[21]

The wear of hybrid composites increases with increase of sliding distance. The highest wear occurs in aluminium alloy, while, with Al/SiC composites, the wear decreases with increase of SiC particle size. With Al/SiC/Gr hybrid composites, the trend is the same, but the wear is much lower than with Al/SiC composites (Fig. 16).

Friction coefficient decreases with the increase of SiC reinforcement particle size. At the same time, with Al/SiC/Gr hybrid composites, the friction coefficient is lower than with Al–SiC composites without graphite (Fig. 17).

Adding of graphite (5%) leads to decrease of friction coefficient due to forming of lubricant layer. It is obvious that mechanical characteristics (porosity, hardness) as well as tribological characteristics (wear intensity and friction coefficient)

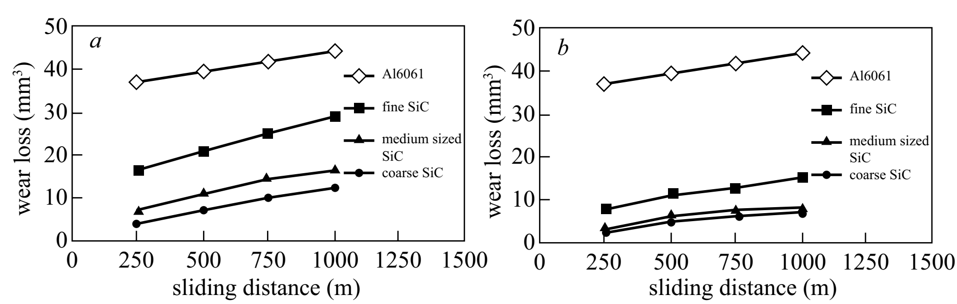

Fig. 16. Dependence between wear loss and sliding distance for Al/SiC composites (*a*) and for Al/SiC/Gr composites[22] (*b*)

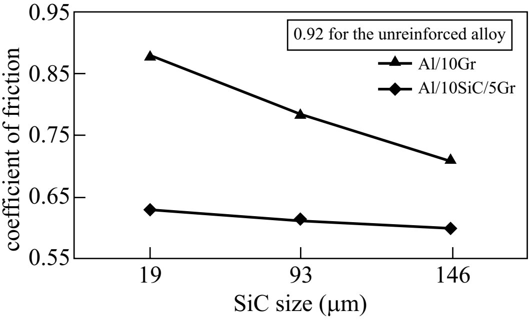

Fig. 17. Dependence between coefficient friction and SiC particle size[22]

of Al/10SiC composite decrease by adding of 5% of graphite or by forming Al/SiC/Gr hybrid composites.

Ames and Alpas[23] have studied tribological behaviour of hybrid composite with A356 base reinforced by 20% of SiC and 3÷10% of graphite. Tribological tests are performed on a block-on-ring contact pair without lubrication. Load size varies from 1 to 441 N. Wear resistance of Al/20SiC/3Gr hybrid composite is approximately equal to wear resistance of Al/20SiC composite at low and medium loads. For loads lower than 20 N, wear of Al/20SiC/3Gr hybrid composite and Al/20SiC composite is 10 times lower than wear of a basic material without reinforcement (A356). Due to hardness of SiC particles, Al/20SiC/3Gr hybrid composite has 1÷2 times higher wear resistance than Al/20SiC/10Gr at higher loads. However, the graphite leads to decrease of counter body wear.

Vencl et al.[24,25] have studied tribological characteristics of hybrid composites with A356 base reinforced by ceramic particles SiC and Al_2O_3 and graphite. Hybrid composites are obtained by compo-casting procedure and T6 heat-treatment regime. When talking about micro-hardness with addition of 10% of ceramic reinforcement (SiC or Al_2O_3), the micro-hardness increases and with addition of 1% of graphite, the micro-hardness decreases below the micro-hardness of a basic material.

Reinforcement particles (SiC or Al_2O_3) are arranged in clusters in composite matrix. Particles arrangement of SiC in clusters is more favourable for mechanical and tribological characteristics in comparison to arrangement of Al_2O_3 particles. Wear resistance increases by adding reinforcement, especially by adding graphite, while the friction coefficient of ceramic reinforced composites is higher than friction coefficient of the basic material. At the same time, friction coefficient of Al/10SiC/1Gr hybrid composite is lower than friction coefficient of the basic material (A356) (Fig. 18).

Lagiewka and co-workers[26] have studied tribological influence of combined reinforcement by silicon–carbide and graphite on a hybrid composite with AlMg10 matrix. Hybrid composites with the following reinforcement content: AlMg10/5SiC/2Gr, AlMg10/5SiC/5Gr, AlMg10/15SiC/2Gr and AlMg10/15SiC/5Gr were tested. Tribological tests are performed on tribometer block-on-disc with load of 50 N and sliding distance of 3000 m. The results show that wear resistance of hybrid composites is higher than wear resistance of AG10

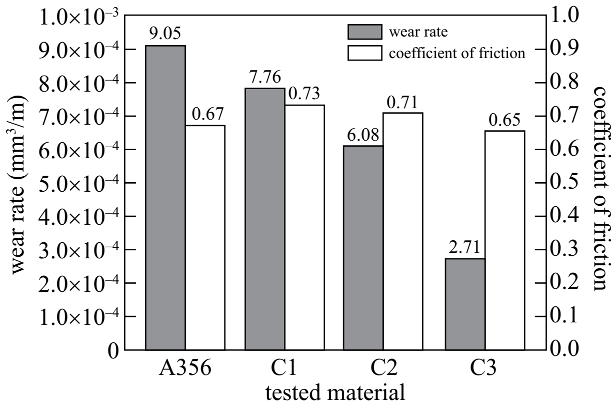

Fig. 18. Resistance to wear and friction coefficient of A356 alloy, C1 ($Al/10Al_2O_3$) composite, C2 (Al/10SiC) composite and C3 (Al/10SiC/1Gr) composite[24]

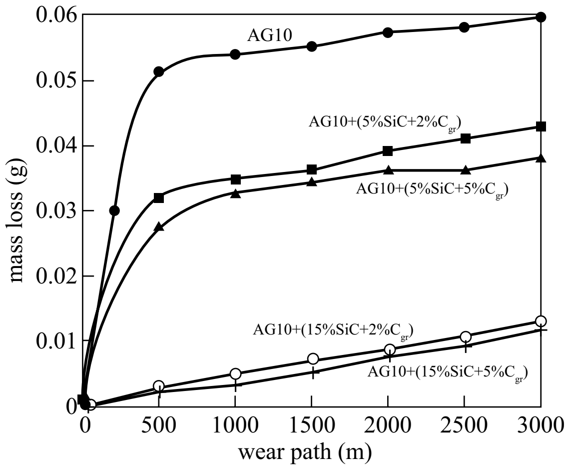

Fig. 19. Dependence between mass loss and sliding distance[26]

basic material. Also, there is higher wear resistance for the same value of SiC with composites with higher graphite content. Thus, the higher wear resistance is found for hybrid composites with 15%SiC and 5%Gr (Fig. 19).

CONCLUSIONS

Hybrid Al/SiC/Gr composites have a lot of better tribological characteristics in comparison to Al–SiC and Al–Gr composites. By changing percentage content of reinforcement, mechanical and tribological characteristics of the obtained hybrid composites with aluminium matrix are changed.

Hybrid composites with aluminium matrix are obtained by different methods of casting (powder metallurgy, squeeze casting, stir casting, etc.). Percentage of silicon–carbide (SiC) ranges from 0÷40% and percentage of graphite – within 0÷13%. Particle sizes of SiC and graphite are different depending on the manufacturer and procedure for obtaining hybrid composites.

Tribological tests of Al/SiC/Gr hybrid composites are performed on tribometers with different contact pairs (block-on-ring, pin-on-disc, block-on-disc, etc.). Tests are performed in accordance with appropriate ASTM standard for different values of loads, sliding distances and sliding speeds.

Results of tribological tests show that friction coefficient of Al/SiC/Gr hybrid composites decreases with the increase of graphite content. Friction coefficient decreases with increase of SiC content all up to 30% and, after that, it increases.

When referring to amount of wear, it decreases with the increase of graphite content (for the same values of SiC). The increase of SiC content also leads to wear decrease or to increase of wear resistance of the tested composites. At the same time, the wear increases with increase of the sliding distance. Increase of the sliding speed and load also leads to wear increase or decrease of wear resistance of Al/SiC/Gr hybrid composites.

The particle size of reinforcement also affects the wear of hybrid composites with aluminium matrix reinforced by SiC and graphite. As the particle size of graphite is bigger, the wear of composite is smaller, and vice versa.

It is obvious that tribological characteristics of Al/SiC/Gr hybrid composites depend on a number of factors, but their characteristics are much better in comparison to Al–SiC and Al–Gr composites.

ACKNOWLEDGEMENT

This paper presents the research results obtained within the framework of a project TR–35021, financially supported by the Ministry of Education and Science of the Republic of Serbia.

REFERENCES

1. M. K. SURAPPA: Aluminium Matrix Composites: Challenges and Opportunities. Sadhana, **28** (1, 2), 319 (2003).
2. M. BABIC, S. MITROVIC, R. NINKOVIC: Tribological Potencial of Zinc–Aluminium Alloys Improvement. Trib Ind, **31** (1, 2), 15 (2009).
3. M. BABIC, S. MITROVIC, B. JEREMIC: The Influence of Heat Treatment on the Sliding Wear Behavior of a ZA-27 Alloy. Trib Int, **43** (1, 2), 16 (2010).
4. M. KANDEVA, L. VASILEVA, R. RANGELOV, S. SIMEONOVA: Wear-resistance of Aluminum Matrix Microcomposite Materials. Trib Ind, **33** (2), 57 (2011).
5. V. S. AIGBODION, S. B. HASSAN, E. T. DAUDA, R. A. MOHAMMED: Experimental Study of Ageing Behaviour of Al-Cu-Mg/Bagasse Ash Particulate Composites. Trib Ind, **33** (1), 28 (2011).
6. B. BOBIC, S. MITROVIC, M. BABIC, I. BOBIC: Corrosion of Aluminium and Zinc–Aluminium Alloys Based Metal–Matrix Composites, Trib Ind, **31** (3, 4), 44 (2009).

7. A. G. KOSTORNOV, O. I. FUSHCHICH, T. M. CHEVICHELOVA, Y. M. SIMEONOVA, G. S. SOTIROV: Self-lubricating Composite Materials for Dry Friction. Trib Ind, **31** (1, 2), 29(2009).
8. M. L. TED GUO, C. Y. A. TSAO: Tribological Behavior of Self-lubricating Aluminium/SiC/Graphite Hybrid Composites Synthesized by the Semi-solid Powder-densification Method. Compos Sci Technol, **60** (1), 65(2000).
9. Ar. RIAHI, At. ALPAS: The Role of Tribo-layers on the Sliding Wear Behaviour of Graphitic Aluminum Matrix Composites. Wear, **251**, 1396 (2001).
10. S. BASAVARAJAPPA, G. CHANDRAMOHAN, K. MUKUND, M. ASHWIN, M. PRABU: Dry Sliding Wear Behavior of Al 2219/SiCp-Gr Hybrid Metal Matrix Composites. J Mater Eng Perform, **15** (6), 668 (2006).
11. S. BASAVARAJAPPA, G. CHANDRAMOHAN: Dry Sliding Wear Behavior of Hybrid Metal Matrix Composites. Mater Sci, **11** (3), 253 (2005).
12. S. BASAVARAJAPPA, G. CHANDRAMOHAN, A. MAHADEVAN: Influence of Sliding Speed on the Dry Sliding Wear Behaviour and the Subsurface Deformation on Hybrid Metal Matrix Composite. Wear, **262**, 1007 (2007).
13. S. SURESHA, B. K. SRIDHARA: Wear Characteristics of Hybrid Aluminium Matrix Composites Reinforced with Graphite and Silicon Carbide Particulates. Compos Sci Technol, **70** (11), 1652 (2010).
14. S. SURESHA, B. K. SRIDHARA: Effect of Addition of Graphite Particulates on the Wear Behavior in Aluminium–Silicon Carbide–Graphite Composites. Mater Design, **31**, 1804 (2010).
15. S. SURESHA, B. K. SRIDHARA: Effect of Silicon Carbide Particulates on Wear Resistance of Graphitic Aluminium Matrix Composites. Mater Design, **31** (9), 4470 (2010).
16. S. SURESHA, B. K. SRIDHARA: Friction Characteristics of Aluminium Silicon Carbide Graphite Hybrid Composites. J Mater Sci, **46**, 1502 (2011).
17. J. LENG, L. JIANG, G. WU, S. TIAN, G. CHEN: Effect of Graphite Particle Reinforcement on Dry Sliding Wear of SiC/Gr/Al Composites. Rare Metal Mater Eng, **38** (11), 2009.
18. J. LENG, G. WU, Q. ZHOU, Z. DOU, X. HUANG: Mechanical Properties of SiC/Gr/Al Composites Fabricated by Squeeze Casting Technology. Scripta Materialia, **59** (6), 619 (2008).
19. S. MAHDAVI, F. AKHLAGHI: Effect of SiC Content on the Processing, Compaction Behavior, and Properties of Al6061/SiC/Gr Hybrid Composites. J Mater Sci, **46** (5), 1502 (2011).
20. S. MAHDAVI, F. AKHLAGHI: Effect of the Graphite Content on the Tribological Behavior of Al/Gr and Al/30SiC/Gr Composites Processed by *in situ* Powder Metallurgy (IPM) Method. Tribol Lett, **44**, 1 (2011).
21. F. AKHLAGHI, S. MAHDAVI: Effect of the SiC Content on the Tribological Properties of Hybrid Al/Gr/SiC Composites Processed by *in situ* Powder Metallurgy (IPM) Method. Adv Mat Res, 1878 (2011).
22. S. MAHDAVI, F. AKHLAGHI: Effect of the SiC Particle Size on the Dry Sliding Wear Behavior of SiC and SiC–Gr-reinforced Al6061 Composites. J Mater Sci, DOI 10.1007/s10853-011-5776-1, 2011.
23. W. AMES, At. ALPAS: Wear Mechanisms in Hybrid Composites of Graphite-20% SiC in A356 Aluminum Alloy. Metall Mater Trans A, **26**, 85(1995).
24. A. VENCL, I. BOBIC, S. AROSTEGUI, B. BOBIC, A. MARINKOVIC, M. BABIC: Structural, Mechanical and Tribological Properties of A356 Aluminium Alloy Reinforced with Al_2O_3, SiC and SiC + graphite particles. J Alloy Compds, **506**, 631(2010).

25. A. VENCL, A. MARINKOVIC: Influence of the Solid Lubricant Particles Reinforcement on Composites Tribological Properties. In: 11th International Conference on Tribology, Belgrade, 2009, p. 78.
26. M. LAGIEWKA, Z. KONOPKA, A. ZYSKA, M. NADOLSKI: Examining of Abrasion Resistance of Hybrid Composites Reinforced with SiC and C_{gr} Particles. Archives and Foundry Engin, **8** (3), 59(2008).

Received 22 May 2012
Revised 28 July 2012