JOURNAL OF AERONAUTICAL MATERIALS
ISSN: 1005-5053

Vol. 42, Issue-05, 2022
pp.277-285

MECHANICAL PROPERTY IMPROVEMENT IN AL6061 REINFORCED WITH STEEL, GRAPHITE AND SIC USING TAGUCHI METHOD

Pushpendra Kumar, Sanjeev Dhaiya
Research scholar, Department of mechanical engineering
Professor, Department of mechanical engineering, University of Technology, Jaipur

Abstract: This research intends to investigate the mechanical and wear behaviour of aluminium-based composites reinforced with wt% of steel, SiC and graphite particles. The wt% of steel, SiC and graphite particles have been oriented by full factorial design of experiment. Taguchi method has been employed for mono-objective optimization of hardness, and tensile strength. From the results, the use of steel particles as replacement of conventional reinforcements such as SiC in AMCs, has great promise for applications where high specific strength, toughness and wear resistance are desired in service. Results revealed that the greatest signal-to-noise ratio for the hardness is attained at the highest level of wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8. Therefore, these parameters combination is the optimum settings. For ultimate tensile strength, a highest signal-to-noise ratio is achieved from the wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8 which indicate the optimum parameter level

Keywords: Aluminium metal matrix composites, steel, graphite, SiC, fabrication, Taguchi method

1. Introduction

Aluminium metal matrix composites (Al MMCs) account for about 69% by mass of metal matrix composites (MMCs) produced annually and used for industrial purposes (Prakash et. al. 2018). This is so as a result of their outstanding physical, mechanical and tribological properties. Al MMCs have been given preference over other frequently used aluminium alloys in recent times as a result of their excellent strength-to-weight ratio (Idusuyi. et. al., 2016). MMCs are designed to bring together the desirable metallic matrix characteristics and the properties of reinforcements particles (Kumar et. al., 2017). Specifically, in the case of Al MMCs, the metallic matrix (aluminium) provides ductility, formability, toughness, electricand thermal conductivities while the reinforcements offer high hardness, modulus, strength, low thermal expansion and high temperature durability (Lavernia et. al., 2017). No monolithic material is yet to be a match for Al MMCs in terms of their combination of profile properties (Surappa et. al., 2003; Rajeswari et. al., 2015). Al MMCs have become choice materials for construction and building purposes (Srivastava, 2017; Akhil, 2018), structural, thermal management and mild steel bearing applications (Alaneme, 2015), for making components such as cylinder liners, rotating blade sleeves, brake drums, cylinder blocks, gear parts, piston crowns, crankshafts, disk brakes and drive shafts (Alaneme, 2017), aerospace and defence (Rawal, 2001) and other fields have drawn even more attention (Ramnath, 2014). Others are precision and optical instruments (Mohn, 1988), rail transport (Hariharasakthi Sudhan, 2018), sporting equipment (Sijo, 2016), air conditioner compressor pistons (Mistry, 2019), and energy (Nieto, 2017). These areas of application point to the fact that a substantial amount of components for which Al MMCs are developed are susceptible to high wear rates (Gargatte, 2013). It is therefore pertinent to study the wear characteristics of these composites to enhance the understanding of their behaviour in service.It has been established that wear characteristics of materials are determined by a number of material and operational conditions in a complex manner (Dixit, 2014).

The use of metallic materials as reinforcement in AMCs, is lately among the strategies deployed to enhance the low ductility and toughness observed in ceramic reinforced AMCs. The selection of metallic materials is based on the good wettability between metals compared with metal and ceramic systems, which enhances interface strength and consequently, load transfer from the matrix to the reinforcement. This is in addition to the inherent ductile nature of the metal reinforcement, which makes them less susceptible to brittle fracture compared to ceramics. In this regard, a number of studies have been carried out to demonstrate the viability of this design strategy, with Ni and Fe being the most reported metallic reinforcement studied (Saravana et. al., 2013; Abdulla et. al., 2016).

This research intends to investigate the structural features, mechanical and wear behaviour of stir cast aluminium-based composites reinforced with steel and graphite particles. The steel particles will be processed through milling of steel chips, which can be cheaply sourced from industrial machining shops. The choice of steel machining chips as starting material is informed by its high strength compared to bulk steel material, arising from the ultra-fine/nano grain structure it is reported to possess. The ultra-fine/nano scale grain structure that develops is a characteristic resulting from the high deformation strains steels sustain during the process of chip formation (Alaneme, 2016).

2. Literature Review

Alaneme et. al. (2019) analysed the structural characteristics, mechanical and wear behaviour of stir cast Al-Mg-Si alloy-based composites reinforced with different weight percent of steel, steel-graphite hybrid mix, and SiC-particles were investigated. The results show that the hardness of the composites increased approximately by 11% with increase in steel particles from 4 to 8 wt. %. For the same range of steel concentration, the ultimate tensile strength also increased with increase in steel wt. %. These strength values were all higher than that of 8 wt. % reinforced SiC by a margin of 3.2–24%. The specific strength and fracture toughness equally followed the same trend with respect to steel concentration with strain to fracture, the exception where slight decrease (less than 4%) is observed. Wong et al. (2006) reported that a continuous metallurgical bond at the insert/alloy interface is achieved in cast iron insert reinforced Al-Si alloy, consequently giving rise to good thermal conductivity and mechanical properties.

Fathy et al. (2015) studied the effect of iron addition on powder metallurgy processed Al-matrix composites. It was reported that iron improved the compressive strength and hardness of the composites but little was reported on its effect on the ductility or toughness. The strengthening mechanism was linked to the grain refinement of the Al matrix, the uniform distribution of the Fe particles, as well as the formation of Al13Fe4 intermetallic compound. The investigation by (Abdulla et. al., 2016) focused on the mechanical properties and wear behaviour of aluminium matrix reinforced with steel machining chips processed by powder metallurgy. The investigation showed that the addition of steel machining chips, resulted in significantly low porosity levels in the aluminium matrix composites, compared with the use of SiC as reinforcement. The mechanical properties as well as the wear resistance, were also improved with the use of the steel machining chips as reinforcement.

The type, nature, shape and size of reinforcements are critical factors in the wear performance of Al MMCs and so careful selection is needed (Sijo et. al., 2016; Dev, 2018). From an investigation on wear behaviour of hybrid Al2219/Gr/B4C composite (Ravindranath et. al., 2017), increase in sliding speed, sliding distance, applied load were found to lead to an increase in the wear rates of base alloy Al2219, Al2219 with 8%B4C and the hybridised composite (Al2219 + 8%B4C + 3%Gr). However, the hybridised composite displayed better resistance to wear probably due to the action of the ceramic particle reinforcements which were present. The particles provided a considerable amount of resistance to the micro cutting of the composite by the abrasive, leading to lessening of the rate at which material was being removed from the surface of the composite.

Sharma et al. (2017) studied wear in an Al-Fly ash reinforced composite. They observed that least wear loss and coefficient of friction values of 0.32 g and 0.12 were obtained at 6 wt% and 4 wt% fly ash content between the tribo-pairs of cast iron surface and MMC surface.

Vedrtnam and Kumar (2018) investigated the wear behaviour of aluminium reinforced with silicon carbide and copper. From the work, it was shown that the most influential parameter on the rate of wear of the composite was weight percentage of the reinforcements. Load and sliding speed were second and third, respectively in the order of dominance while sliding distance had the least effect. Singh et al. (2017) studied the friction and wear behaviour of aluminium alloy (Al 7075) and an Al MMC containing silicon carbide reinforcement particles under dry condition at different sliding distance. It was concluded from the work that wear rate of the silicon carbidebased Al MMC was less than that of the aluminium matrix alloy by 30–40%. This is in line with the observation from another study by Hemanth et al. (2018), on the tribological properties of Al MMC–SiC composites. The results from their work revealed that the resistance to wear by the SiC reinforced aluminium composite was higher by about 14%compared to that of the aluminium alloy. A natural mineral, rutile (TiO2) was used as reinforcement in a hybrid composite of aluminium base. Powder metallurgy was applied by Kumar and Rajadurai (2016) to synthesise the composite.

In their work on the investigation of wear characteristics of Al–SiC composites, Singla et al. (2009) submitted that at a fixed sliding velocity, the wear rate increased linearly as the sliding distance increased. Clustering of the reinforcing SiC particles and non-uniform blending with the aluminium matrix was said to have been the reason for the trend. The investigation of the tribological properties of Aluminium/Alumina/Graphite Al MMC, by Radhika et al. (2011) gave a somewhat contrary result. The results from their work showed that as the sliding distance increased, the wear rate and coefficient of friction decreased. The inverse relationship was attributed to the abrasion resistance brought about by the presence of hard alumina particle and the reduction of wear due to a layer formed by graphite between the sliding pin surface and the composite.

3. Research method

The Al alloy with chemical composition presented in Table 3.1, served as the metal matrix for the Al-based composite development. Matrix used in this study is aluminium 6061 alloy whose composition is in Table 1.

Table 1: Chemical Composition of AA6061Aluminum Alloy

Element	Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
Wt%	0.85	0.69	0.14	0.24	0.02	0.02	0.004	0.03	Bal

Aluminium 6061 is most versatile and extensively used aluminium alloys in 6000 series. Magnesium and silicon are major alloying elements in aluminium 6061 alloy. Aluminium 6061 possesses good strength, high machineability, good hardness and also light in weight. But some of properties such as low wear resistance has limited the application of this material. Aluminium 6061 alloy was selected as matrix owing to its cost and useful specific properties.

The reinforcement materials selected for investigation are steel particulates, graphite and silicon carbide respectively. Steel particulates, graphite and silicon carbide were selected as reinforcements for the composite production. The steel particulates were processed from Steel machining chips obtained from boring operation on medium carbon steel, graphite and silicon carbide. The steel chips, which were initially of average particle size of 600μm, were ball milled to 100μm passing, before being used as reinforcement particles. The graphite and silicon carbide, were both of analytical pure grades with an average particle size of 30μm. Both the graphite and silicon carbide were purchased from a local vendor.

The experimental plan was formulated considering three parameters (variables) and three levels. The levels of these variables chosen for experimentation are given in Table 2. The ranges of the selected parameters for design of experiment were based on Alaneme et al. (2019).

Table 2: Process variables and their limits

.

Parameters/Factors		Level		
		1	2	3
A	Wt. % of steel	4	6	8
B	Wt. % of graphite	1	2	3
C	Wt. % of SiC	4	6	8

4. Results and discussion

Mechanical Properties of hybrid Composites

The samples of Al6061 alloy-based hybrid composites are fabricated with varying weight percentage of (4, 6 and 8 wt %) steel, (1, 2 and 3 wt %) graphite and (4, 6, 8 wt%) SiC particles are prepared by stir casting process. The experimental work for the fabrication of Al6061 hybrid composite is discussed in the previous chapter. The test specimens are machined by wire-cut electrical discharge machine as per the ASTM standards to find out the density, hardness, tensile strength and flexural strength of composites.

The hardness of Al6061 reinforced with steel, graphite and SiC particles hybrid composite is shown. The hardness test values are measured at four locations. Each sample and the average of four values of hardness in each combination are tabulated. The hardness of composites against cumulative reinforcement's wt% is plotted in the Figure 1.

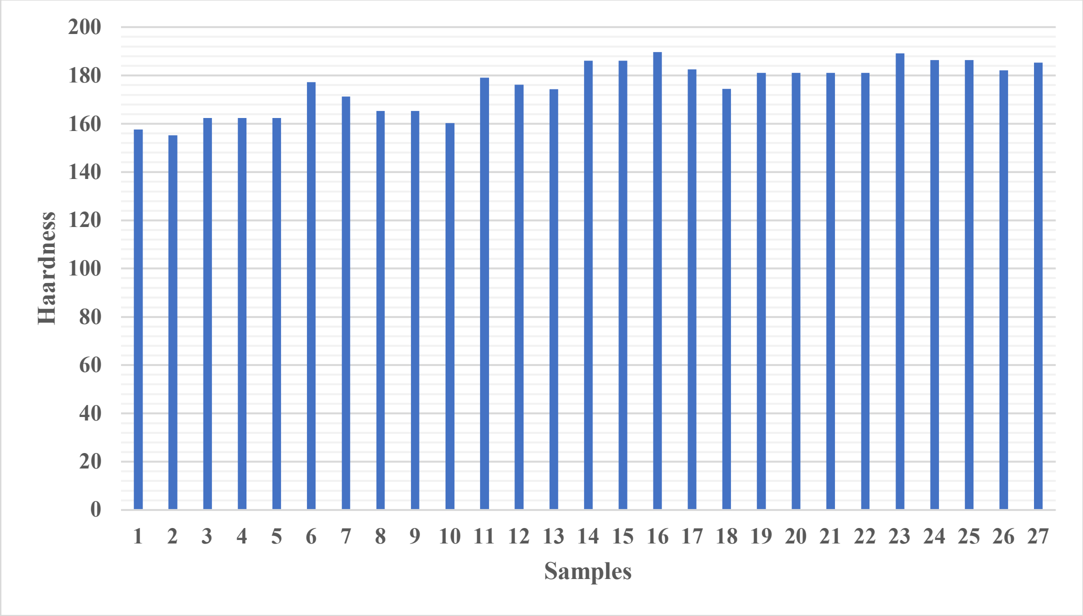

Fig. 1: Variation of hardness across samples

Two tensile test specimens are prepared for testing purpose and the average of two tensile test values are reported. In this research, the test results show that improvement in tensile strength while increasing the wt% of steel, graphite and SiC particles.

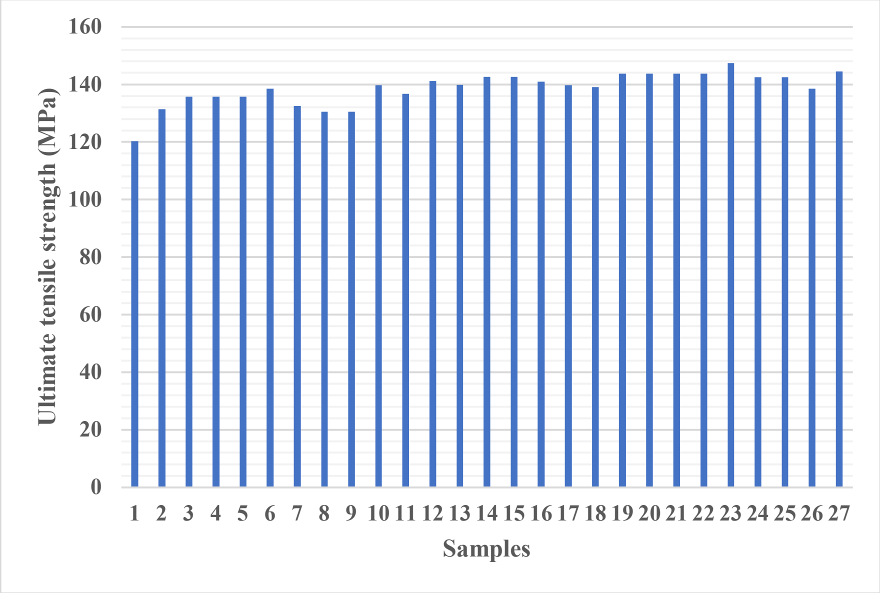

Fig. 2: Variation of ultimate tensile strength across samples

Optimisation

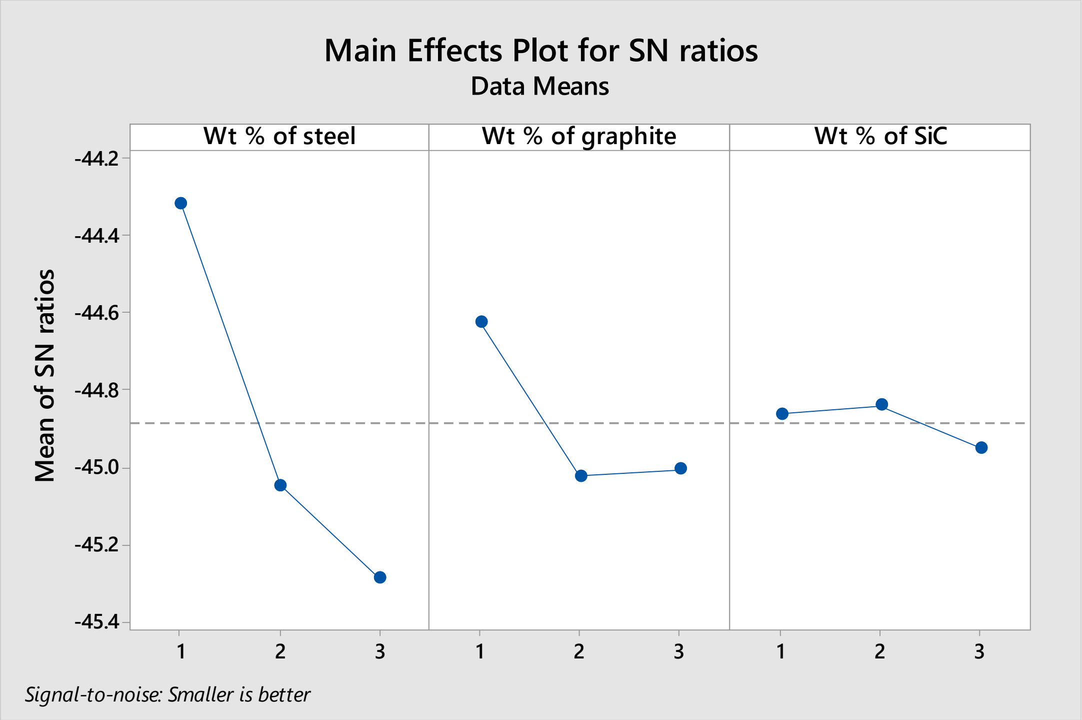

Fig. 3: S/N ratio plot for hardness

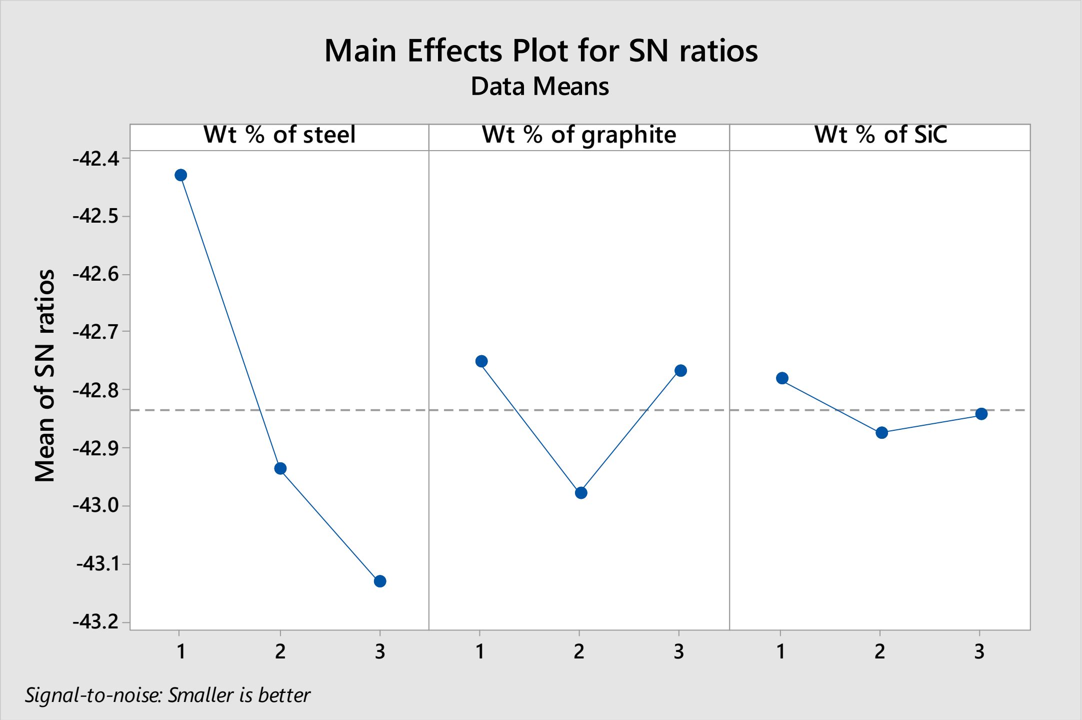

Fig. 4: S/N ratio plot for ultimate tensile strength

It is noticeable from the Fig. 3-4 that the highest signal-to-noise ratio of specific wear rate is achieved from the wt% of steel = 6; wt% of graphite = 2; wt% of SiC = 8 which indicate the optimum parameter level. Similarly, the greatest signal-to-noise ratio for the hardness is attained at the highest level of wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8. Therefore, these parameters combination is the optimum settings.

Table 3: Optimum parameter obtained from Signal to Noise Ratios (larger is better and smaller is better)

Response	**Optimum settings**	
Hardness	A3B2C3	wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8
Ultimate tensile strength	A3B2C2	wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8
Flexural strength	A3B2C1	wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 4
Wear rate	A2B2C3	wt% of steel = 6; wt% of graphite = 2; wt% of SiC = 8

5. Conclusion

This research intends to investigate the mechanical and wear behaviour of aluminium-based composites reinforced with wt% of steel, SiC and graphite particles. The wt% of steel, SiC and graphite particles have been oriented by full factorial design of experiment. From the results, the use of steel particles as replacement of conventional reinforcements such as SiC in AMCs, has great promise for applications where high specific strength, toughness and wear resistance are desired in service. Taguchi S/N ratio-based optimization revealed that a highest signal-to-noise ratio of specific wear rate is achieved from the wt% of steel = 6; wt% of graphite = 2; wt% of SiC = 8 which indicate the optimum parameter level. Similarly, the greatest signal-to-noise ratio for the hardness is attained at the highest level of wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8. Therefore, these parameters combination is the optimum settings. For ultimate tensile strength, a highest signal-to-noise ratio is achieved from the wt% of steel = 8; wt% of graphite = 2; wt% of SiC = 8 which indicate the optimum parameter level.

References

1. Prakash JU, Ananth S, Sivakumar G, Moorthy TV. Multi-objective optimization of wear parameters for aluminium matrix composites (413/B 4 C) using grey relational analysis. Mater Today 2018; 5: 7207–16, http://dx.doi.org/10.1016/j.matpr.2017.11.387.
2. Idusuyi N, Ajide OO, Oluwole OO, Arotiba OA. Electrochemical impedance study of an Al6063–12%SiC–Cr composite immersed in 3 wt.% sodium chloride. Procedia Manuf 2016;7: 413–9, http://dx.doi.org/10.1016/j.promfg.2016.12.019.
3. Kumar SM, Pramod R, Govindaraju HK. Evaluation of mechanical and wear properties of aluminium AA430reinforced with SiC and MgO. Mater Today 2017;4: 509–18, http://dx.doi.org/10.1016/j.matpr.2017.01.051.
4. Ma K, Lavernia EJ, Schoenung JM. Particulate reinforced aluminum alloy matrix composites – a review on the effect of micro constituents. Rev Adv Mater Sci 2017;48: 11–4.

5. Surappa MK. Aluminium matrix composites: challenges and opportunities. Sadhana 2003;28: 319–34.
6. Rajeswari B, Amirthagadeswaran KS, Anbarasu K.Investigation of mechanical properties of aluminium7075–silicon carbide–alumina hybrid composite using Taguchi method. Aust J Mech Eng 2015; 3: 127–35.
7. Srivastava A. Recent advances in metal matrix composites (MMCs): a review. Biomed J Sci Tech Res 2017;1: 520–2, http://dx.doi.org/10.26717/BJSTR.2017.01.000236.
8. Akhil R. A study on recent trends in the applications of metal matrix composites. Int J Res Appl Sci Eng Technol 2018; 6:172–80.
9. Alaneme KK, Sanusi KO. Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite. Eng Sci Technol Int J 2015:1–7, http://dx.doi.org/10.1016/j.jestch.2015.02.003.
10. Alaneme KK, Ekperusi JO, Oke SR. Corrosion behaviour of thermal cycled aluminium hybrid composites reinforced with rice husk ash and silicon carbide. J King Saud Univ –Eng Sci 2016, http://dx.doi.org/10.1016/j.jksues.2016.08.001.
11. Rawal SP. Metal–matrix composites for space applications. JOM 2001; 53: 14–7, http://dx.doi.org/10.1007/s11837-001-0139-z.

12. Ramnath BV, Elanchezhian C, Annamalai R, Aravind S,Atreya TSA, Vignesh V, et al. Aluminum metal matrix composites – a review. Rev Adv Mater Sci 2014; 38: 55– 60.
13. Mohn WR, Vukobratovich D. Recent applications of metal matrix composites in precision instruments and optical systems. J Mater Eng 1988; 10:225–35, http://dx.doi.org/10.1007/BF02834166.
14. Hariharasakthisudhan P, Jose S, Manisekar K. Dry sliding wear behaviour of single and dual ceramic reinforcements premixed with Al powder in AA6061 matrix. J Mater Res Technol 2018:1–9.
15. Sijo MT, Jayadevan KR. Analysis of stir cast aluminium silicon carbide metal matrix composite: a comprehensive review. Procedia Technol 2016; 24: 379–85, http://dx.doi.org/10.1016/j.protcy.2016.05.052.
16. Mistry JM, Gohil PP. Experimental investigations on wear and friction behaviour of Si 3 N 4p reinforced heat-treated aluminium matrix composites produced using electromagnetic stir casting process. Composites Part B2019; 161: 190–204.
17. Nieto A, Yang H, Jiang L, Schoenung JM. Reinforcement size effects on the abrasive wear of boron carbide reinforced aluminum composites. Wear 2017; 390–391:228– 35.
18. Gargatte S, Upadhye RR, Dandagi BSW, Venkatesh S, Desai Srikanth R. Preparation & characterization of Al-5083 alloy composites. J Miner Mater Charact Eng 2013; 1:8–14.
19. Dixit G, Khan MM. Sliding wear response of an aluminium metal matrix composite: effect of solid lubricant particle size. Jordan J Mech Ind Eng 2014; 8: 351–8.
20. Saravanakumar A, Sivalingam S, Rajesh L. Dry sliding wear of AA2219/Gr metal matrix composites. Mater Today Proc 2018; 5: 8321–7.
21. Wong WLE, Gupta M, Lim CYH. Synthesis and characterization of hybrid aluminium composites reinforced with Ni particulates and interconnected Fe mesh. Solid State Phenom 2006; 111:39–42.

22. Fathy A, El-kady OO, Mohammed MM. Effect of iron addition on microstructure, mechanical and magnetic properties of Al-matrix composite produced by powder metallurgy route. Trans Nonferrous Met Soc China 2015; 25: 46–53.

23. Dev P, Charoo MS. Role of reinforcements on the mechanical and tribological behavior of aluminum metal matrix composites – a review. Mater Today Proc 2018;5: 20041–53.

24. Sharma VK, Singh RC, Chaudhary R. Effect of fly ash particles with aluminium melt on the wear of aluminium metal matrix composites. Eng Sci Technol Int J 2017;20: 1318–23.

25. Vedrtnam A, Kumar A. Fabrication and wear characterization of silicon carbide and copper reinforced aluminium matrix composite. Mater Discov 2018;1, http://dx.doi.org/10.1016/j.md.2018.01.002.

26. Singh KK, Singh S, Shrivastava AK. Comparison of wear and friction behavior of aluminum matrix alloy (Al 7075) and silicon carbide based aluminum metal matrix composite under dry condition at different sliding distance. Mater Today Proc 2017;4: 8960–70, http://dx.doi.org/10.1016/j.matpr.2017.07.248.

27. Kumar CAV, Rajadurai JS. Influence of rutile (TiO2) content on wear and micro hardness characteristics of aluminium-based hybrid composites synthesized by powder metallurgy. Trans Nonferrous Met Soc China 2016; 26: 63–73, http://dx.doi.org/10.1016/S1003-6326(16)64089-X.

28. Mathan Kumar N, Senthil Kumaran S, Kumaraswamydhas LA. High temperature investigation on EDM process of Al2618 alloy reinforced with Si3N4, ALN and ZrB2in-situcomposites. J Alloys Compds 2016;663: 755–68.

29. Subramanian M, Sakthivel M, Sooryaprakash K, SudhakaranR. Optimization of end mill tool geometry parameters forAl7075-T6 machining operations based on vibration amplitude by response surface methodology. Measurement2013; 46: 4005–22.

30. Basavarajappa S, Chandramohan G. Wear studies on metal matrix composites: a Taguchi approach. J Mater Sci Technol2005; 21: 845–50.