Journal of Advanced Research in Mechanical Engineering and Technology
Volume 6, Issue 1&2 - 2019, Pg. No. 13-22
Peer Reviewed Journal

Review Article

Wear Behaviour of Aluminium Matrix Hybrid Composites: A Review

Shivdev Singh[1], Ajay Gupta[2], Vishal S Sharma[3]

[1,2,3]Department of Industrial and Production Engineering, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar 144011, Punjab, India.
DOI: https://doi.org/10.24321/2454.8650.201903

I N F O

Corresponding Author:
Shivdev Singh, Department of Industrial and Production Engineering, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar 144011, Punjab, India.
E-mail Id:
er.shivdevsingh@gmail.com
Orcid Id:
https://orcid.org/0000-0003-3194-2757
How to cite this article:
Singh S, Gupta A, Sharma. Wear Behaviour of Aluminium Matrix Hybrid Composites: A Review. *J Adv Res Mech Engi Tech* 2019; 6(1&2): 13-22.

Date of Submission: 2019-09-09
Date of Acceptance: 2019-09-16

A B S T R A C T

This review focus on the effect of reinforcement and different manufacturing techniques on wear and mechanical properties aluminium matrix composites and hybrid composites. These materials have capacity to satisfying the demands of advanced engineering materials applications. These difficulties are satisfied due to improved mechanical properties, conventional processing technique and reducing fabrication cost of aluminium composites. In powder metallurgy, the crucial issue is the selection of sizes of the matrix and reinforcement powders, whereas a major challenge in liquid metallurgy is wettability between the reinforcement particles and molten alloy. The addition of Al_2O_3 particles in matrix increases the mechanical strength and wear resistance of composites. However, incorporation of these particles can reduce the wear performance of Al composites under severe conditions. The addition of graphite particles helps in the formation of a thick layer on the wear surface. It was found that the mechanical and wear properties of the single reinforcement composites are better as compared to pure aluminium and aluminium alloys regardless of the aluminium matrix composites fabrication technique. Further, it was also established that most of the hybrid composites demonstrate better mechanical and tribological properties as compared to single reinforcement composites.

Keywords: Aluminium, Metal Matrix Composites, Hybrid Metal Matrix Composites, Graphite, Alumina, Friction Stir Processing

Introduction

The composite material is a mixture of two or more materials unsolvable in each another and retain properties which are better to any of the constituent materials. The matrix materials are categorized as Metal Matrix Composites (MMCs), Ceramic Matrix Composites (CMCs), Polymer Matrix Composites (PMCs) and Carbon Matrix composites.[1] Metal matrix composites are commonly used due to high temperature resistance, moisture, radiation, thermal and electrical conductivities.[2] The most popular reinforcement materials are Al, Mg, Ti, Cu etc. Particulate reinforced aluminium composites are suitable for tribological applications due to low cost and better plastic forming capability than fiber/ whisker composites.[3] There are different reinforcement materials are Fly ash[4], Al_2O_3, [5]SiC, [6]B_4C,[7] solid lubricants such as graphite[8] and MoS_2.[9] In the automobile, cycle and aerospace industries, many of the components are being switched to the composite materials from steel due to more strong and lighter weight. This helps to reduce the weight of components of different industries.[10] The particulate like alumina and graphite was incorporated in the Aluminium Matrix Composites (AMCs), these materials enhanced strength and wear resistance as compared to aluminium. AMCs combined the properties of matrix materials (ductility and toughness)[11] with ceramic properties of reinforcements (high hardness and high modulus),[12] to generate a new material with combination of properties of both matrix and reinforcement.[13] In the last two decades, because of their better properties particulate AMCs were used widely in automotive industries and in specialized areas such as in aeroplane and defence industry[14] and are also used as tribological parts in some vehicles due to their light weight and better wear properties.[15] AMCs have been revealed a considerable advancement in tribological properties, such as sliding and abrasive wear resistance and seizure resistance.[16] These were also applied in electronic packaging industry due to their low coefficient of thermal expansion.[17] AMCs were known as the most important material in the current time because of their enhanced engineering properties, such as their better wear resistance, low density, specific strength and stiffness, as compared to aluminium alloy.[18] The single reinforced materials improved hardness, strength of the composites but at the same time wear resistance was low.

Hybrid aluminium matrix composites are composites in which two or more than two reinforcements is used in a single matrix. It improved the mechanical properties and wear resistance of materials.[19] Now a days, the cylinder liners, brake drums, crank-shafts of automotive and the aerospace industries were manufactured by HAMCs, because of their high strength, light weight and thermal stability.[20] This paper presents a detailed review of alumina and graphite reinforced in aluminium matrix composites and also discussed hybrid aluminium matrix composites of different reinforcement with different manufacturing method regarding their improved mechanical and tribological properties.

Review on Aluminium Matrix Composites and Hybrid Aluminium Matrix Composites with their Wear Behavior

While aluminium is matrix material, the composites fabricated are known as aluminium matrix composites (AMCs). The composites obtained by incorporation of two or more than two reinforcements in aluminium matrix are called aluminium matrix hybrid composites (HAMCs). The direct and indirect strengthening are two strengthening mechanism for AMCs. The matrix transfers their load-bearing capacity to reinforcementis known as direct strengthening mechanism. There are several theories which explain the load transfer effects like shear lag theory[21] and homogenization method.[22] In shear lag theory, the transfer of load is due to shear stress established at particle matrix boundary and particles bear some portion of load. In homogenization method, it maybe due to stress distribution between reinforcement and matrix in a volume average sense. In indirect strengthening mechanism, reinforcement transfers their load-bearing capacity on the matrix. It can be understood by changes in microstructure or deformation mode. The indirect mechanism is better in terms of improving the properties due to reinforcement particles transfer their load to matrix, which causes refinement of microstructure and improved the mechanical as well as wear properties.[23]

Fabrication Methods

The fabrication processes for AMCs can be categorized based on primary methods such as treating the metal matrix in a liquid or a solid form. The fabrication methods have a significant impact on the mechanical properties as well as the cost of production. Particulate-reinforced AMCs materials may be fabricated by bulk processing or applied as coatings. This section aims to discuss AMCs materials produced only through bulk processing. This section contributes an outline of the different methods available for the fabrication of AMCs.

Solid State Processing

Solid state production of AMCs is the process of bonding matrix and reinforcements materials because of mutual diffusion arising between them in solid phase at a higher temperature and under pressure. The main processes under this type are as follows:

- Friction Stir Processing:

In this method, the composites are fabricated when the matrix is in solid state condition. This is done using the same methodology as Friction Stir Welding (FSW). In FSP, a cylindrical rotating tool with a concentric pin and shoulder is plunged into the material surface. Localized heating is produced by friction between the rotating tool and the work piece to raise the local temperature of the material to the hot working range is produced due to friction between rotating tool and work piece, where plastic deformation can be done easily. When the appropriate working temperature is reached, the tool is traversed along the line of interest. It is extruded/ forged, consolidated and cooled under hydrostatic pressure conditions. It is effective and efficient technique which can be used to refine microstructure and to fabricate MMCs.[24]

- Ball Milling:

In this process, a homogeneous material is obtained by blending the powder in a vial with balls made up of hardened steel or zirconia (so called ball milling in which high energy collision of balls and vial leads to the repeated cold welding and fracturing of powder and finally preparation of alloyed powder).[25]

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

- Powder Metallurgy:

It allows uniform dispersion of hybrid particulates[26], duly admixed and pressed together to desired shapes.On sintering elemental powders bond to give desired properties. Powder metallurgy composites can be produced exactly as net shaped components finished to high accuracy[27]. Though compacted powders allow relatively higher quantity of dispersed material, yet they remain obsessed with extra porosity in the final composite.[28]

Liquid Metallurgy Techniques

In this process, the discontinuous phase (reinforcement) is incorporated into continuous phase (metal matrix). The molten metal is poured into various mould of desired shapes by conventional casting. The main processes under this category are as follows:

- Stir Casting:

The process of stir casting came into existence in 1968 through S. Ray. Stir casting is a procedure of mixing dispersed phase ceramic particles or short fibres with a molten matrix metal using mechanical stirring. It is most cost effective method for bulk production and intricate shapes.[29]

- Compo Casting:

Compo casting is the process in which when the melt is solidifying, it is dynamically unsettled and reinforcement particles are added to this solidifying melt. The primary solid particles which are formed in the semi solid melt causes the entrapment of reinforcement particles. It reduces their segregation and agglomeration due to gravity which resulted into better wettability of reinforcement particles with the matrix.[30]

- Squeeze Casting:

Squeeze casting technique is a combination of gravity die casting and closed die forging. In this methods, molten composite is transferred into the preheated die and exposed under a fixed pressure during solidification of casting.[31]

- Spray Deposition Methods:

In this method, atomized molten material droplets with a very high velocity are impressed on a preheated substrate, the reinforcing particles are also co-impacted with the melt spray allowing reinforcement particles engulfment in the molten or partially molten metal droplets to form acomposite. AMCs processed by spray deposition technique is relatively inexpensive with cost that is usually intermediate between stir cast and PM processes.[32]

Out of these two methods liquid phase process is more effective and efficient than solid state because solid state process is time consuming and costly[33], but stir casting is very simple, most cost effective method and its cost is very low as compared to other method in case of mass production. [34] Consequently, in the present time, stir casting is the greatest feasible and predominant method for the fabrication of the particulate-reinforced AMCs.

Comparison of mechanical and wear properties of aluminium alloy against AMCs (Table 1), shows the overall details of composites in comparison of aluminium matrix. From this table, it is clear that mechanical and wear properties of single reinforced composites are superior than that of monolithic materials in all composites irrespective of manufacturing process.

Comparison of mechanical and wear properties of aluminium alloy/ composites/ hybrid AMCs (Table 2), shows overall properties of hybrid composites as compared to matrix and composites. From this table, it is clear that both the mechanical and wear properties of the hybrid composites were enhanced than that of matrix alloy and in most of the cases the wear resistance of hybrid composites amplified due to addition of other reinforcement.

Conclusion

The mechanical and wear properties of composites and hybrid composites are discussed in this review article.

- It has been reviewed from the state of art that the aluminium matrix composites and hybrid composites are mostly fabricated by solid state and liquid metallurgy process.
- It follows while Powder Metallurgy (P/M) is significant technique for processing of these aluminium matrix composites, wherein it is easy to design uniform distribution of reinforcement particles[28]. However, because of component's shape limitations the die development is a costly process and the process is still obsessed with porosity in the composite.
- It was noted that for the fabrication of aluminium matrix composites and hybrid composites, stir casting is recommended by the researcher due to its simplicity, cost effective and suitable for mass production as compared to other fabrication process.
- The hybrid aluminium matrix composites can be fabricated with different combinations of reinforcements to achieve desirable mechanical properties not available in single reinforced composites.
- It is evident that hybrid composites possessed superior mechanical properties with ceramic reinforcement and also wear properties are enhanced due to presence of solid lubricants as compared to composites and pure aluminium materials.

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

Table 1.Composites Properties

Matrix	Reinforcement	Fabrication process	Mechanical properties	Wear properties	Result	Ref.
AA6061	Gr	Powder metallurgy	-	Wear	Wear resistance was improved than that of unreinforced aluminium matrix	35
Al2024	Gr	In situ powder metallurgy	-	Wear and Friction	Wear and friction was showed downward trends when the percentage of graphite particles reached up-to half weight percentage	36
Al-Sialloy	Gr	Laser Sintered	-	Wear	The formationof lubricating film by graphite particles improved wear resistance	37
Al-Mg-Si alloy	Al_2O_3	Stir casting	Hardness, tensile strength	Wear	Mechanical and wear properties were enhanced as compared to matrix. The mechanical properties were increased with increased reinforcement content	38
Al6061	SiC, Al_2O_3 and CeO_2	Liquid metallurgy	Micro-hardness	Wear	Micro-hardness and tribological properties of all composites were enhanced as compared to matrix. Wear resistance improved with increase in reinforcement in all composites	39
Al2024	Al_2O_3	Stir casting	-	Wear	Wear resistance was superior than that of matrix and amplified with increased content of reinforcement	40
Al2024	Gr	Powder metallurgy	-	Wear	Wear resistance was enhanced than that of monolithic material. It was improved with increased reinforcement	41
A356	Al_2O_3	Stir casting, compo casting	UTS, yield strength, Hardness compression strength	-	The mechanical properties were improved with reinforcement content irrespective of manufacturing process as compared to matrix material	42
A359	Al_2O_3	Electromagnetic stir	Hardness, tensile strength	-	Hardness and tensile strength was enhanced with increased reinforcement content	43
Al2024	Al_2O_3	Stir casting method and applied pressure	Hardness, tensile strength	-	The mechanical properties were enhanced with increased reinforcement content	44
AAA7075	Al_2O_3	Conventional liquid casting	-	Wear	Wear resistance and coefficient of friction was enhanced than the matrix. These were increased with increase in reinforcement content	45

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

AA7075	Gr	Liquid casting	Tensile strength, hardness	Wear	Wear resistance enlarged by addition of graphite (Gr) as reinforcement but mechanical properties declined with increased Gr content	46
Al 7075	Nano-silicon carbide (SiC)	Stir casting	Nano-silicon carbide (SiC)	Wear	Wear resistance of composites were higher than the matrix material, wear rate was reduced with enhancing weight % of SiC	47
Al 6061, Al 7075	B_4C Al_2O_3,Gr and SiC	Liquid metallurgy	Yield strength	-	Better yield strength graphite particles reduced tensile strength, compression strength and hardness	48
(AA7075)	Graphite	Stir Casting	Hardness, tensile strength	Wear	The hardness and tensile strength decreased with an increased weight percentage graphite. Wear resistance was improved up to certain limit	49
Al-356	Cupper coated -Al2O3	Vortex method	Hardness, compressive strength, yield stress, tensile strength	-	The hardness, compressive strength, yield stress, tensile strength and elongation of the composites were enhanced	50
AA7075	Alumina nano particles	Stir casting	Hardness, tensile strength	-	The mechanical properties were enhanced as compared to matrix material	51
Al-16Si-5Ni-	Graphite 5%	Stir casting	-	Wear	The composite shown better tribological due to presence of graphite particles in the composites	52
Al6082	1% Al2O3 and 3% SiC and 0 to 6% graphite particles by weight	Stir casting	Hardness, tensile strength stiffness	Wear	The hardness, tensile strength and stiffness was enhanced. The coefficient of friction and wear rate of PAMC decreased with graphite contents	53

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

Table 2.Hybrid Composite Properties

Matrix	Reinforcement	Fabrication process	Mechanical properties	Wear properties	Result	Ref.
AA6061	Al_2O_3+SiC	Stir casting	-	Wear	Dry sliding wear was improved as compared to aluminium matrix	54
Al 7075	SiCwt% 7 (27-33 µm) Gr 3% (20-25 µm) with	Vortex method	-	Wear rate	Specific wear rate of hybrid composites was improved	55
AA6061	SiC+Gr	Semi solid powder	Fracture toughness, hardness	Wear	Fracture toughness and hardness declined with rise in graphite content while the wear rate of composites improved as the graphite content increased up to 5% and then reduced to a lower value for an 8% addition of graphite reinforcement	56
AA 7075	SiC, alumina, fly ash (3,6,9 wt%)	Stir casting	Tensile strength, hardness	-	The tensile strength and hardness of Aluminium hybrid metal matrix showed upward trend with the increased weight percentage of hybrid reinforced particles	57
AA7075,	nano composite (% alumina) and hybrid composites	Squeeze casting	Hardness, tensile strength	-	The hardness and tensile strength was more than the base metal for both composites and hybrid composites	58
AluminiumSiC	Silicon carbide, graphite and alumina	Stir casting	Hardness	-	The hardness was increased with weight fraction of reinforcement material	59
Al-Mgalloy	SiC+Al_2O_3	Pressure infiltration	Hardness, compression strength, impact toughness	Wear	Dry sliding wear enhanced with increased amount of silicon carbide and alumina. It was also resulted in increased mechanical properties	60
Al2219	SiC+Gr	Stircasting	-	Wear	Wear resistance was superior than unreinforced materials	61
Al-Si-10Mg	Al_2O_3+Gr	Stircasting	-	Wear	Dry sliding wear was increased with increased graphite contents	62
Al2024	SiC+Gr	Powder metallurgy	-	Wear	Wear resistance was enlarged than monolithic materials	63
Al2024	SiC+Gr	Powder metallurgy	-	wear	Wear resistance was better than the matrix materials	64

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

Al (99% Pure)	Al_2O_3+SiC	Stir casting	Hardness	Wear	Both the hardness and wear resistance were upgraded as compared to pure aluminium matrix. The wear resistance of hybrid composite was improved than the composites	65
LM-25	SiC+Gr	Stir casting	Hardness	Wear	The hardness ductility and wear resistance were superior than aluminium matrix. The wear resistance of hybrid composite was increased than the composites	66
LM-25	SiC + Gr, SiC+ FA	Stir casting	Tensile strength, hardness	Wear	Tensile strength, hardness and wear resistance was superior than that of pure aluminium	67
A332	SiC+Al_2O_3	Stir casting	Tensile strength	-	Tensilestrength of hybrid composite amplified than pure matrix	68
AA6061	SiC + Al_2O_3	FSP	-	Wear	Wear resistance of hybrid composites were improved as compared to alloy and composites composite increased	69
Al-Mg-Si	RHA + Al_2O_3	Double stir casting	-	Wear	Wear resistance of Al_2O_3-reinforced composite increased with increase in rice husk ash	70
AA6351	SiC+Al_2O_3,	Stir casting	Tensile strength, ductility	-	Both tensile strength and ductility hybrid composite were enhanced than that of matrix but improved result obtained in SiC + TiC-reinforced composites-82	71
AA6061	SiC + Al_2O_3,	FSP	Hardness	Wear	Hardness, ductility and wear resistance of hybrid composites were recovered than that of base matrix but better result attained in SiC + Al_2O_3-reinforced hybrid composites	72
AA6061 and AA7075	B_4C + Gr	Stir casting	Hardness	Wear	Hardness and wear resistance was amplified than that of pure metal in both hybrid composite, but hardness and ductility was improved in case of AA7075 while wear resistance was enhanced in AA6061 case	73
AA7075	Al_2O_3+Gr	Liquid metallurgy	Hardness, tensile and compressive strength	Wear	The mechanical properties were enhanced than that of pure aluminium matrix and increased with increasing the volume fraction of reinforcement while the wear resistance of hybrid composite increased due to presence of Gr particles which acts as a self- lubricating material	74

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903

References

1. Surappa MK. Microstructure evolution during solidification of DRMMCs: state of art. *J Mater Process Technol* 1997; 63: 325-333.
2. Rajan TPD, Pillai RM, Pai BC. Reinforcement coatings and interfaces in aluminium metal matrix composites. *Journal of Materials Science* 1998; 33(14): 3491-3503.
3. Uthayakumar MS, Aravindan S, Rajkumar K. Wear performance of Al-SiC-B_4C hybrid composites under dry sliding conditions. *Materials & Design* 2013; 47: 456-464.
4. Thareja P, Shalom A. Processing Aluminium Fly Ash Composites via Parametric Analysis of Stir Casting. *J Adv Res Manu Mat Sci Metall Engi* 2016; 3(3&4).
5. Sajjadi SA, Zebarjad SM. Microstructural analysis and mechanical properties of aluminium matrix nanocomposites reinforced with uncoated and Cu-coated alumina particles. M*ater Sci Eng A* 2014; 607: 81-88.
6. Knowles AJ et al. Microstructure and mechanical properties of 6061 Al alloy based composites with SiC nanoparticles. *Journal of Alloys and Compounds* 2014; 615: S401-S405.
7. Yamaguchi M, Fanqiang M, Kosty F et al. Powder metallurgy routes toward aluminium boron nitride nanotube composites, their morphologies, structures and mechanical properties. *Materials Science and Engineering: A* 2014; 604: 9-17.
8. Liu B, WenMao H, HaoWei W et al. Study on the load partition behaviors of high particle content B4C/Al composites in compression. *Journal of Composite Materials* 2014; 48(3): 355-364.
9. Deaquino-Lara R, Soltani N, Bahrami A et al. Tribological characterization of Al7075-graphite composites fabricated by mechanical alloying and hot extrusion. *Materials & Design* 2015 67: 224-231.
10. Kanthavel K, Sumesh KR, Saravanakumar P. Study of tribological properties on Al/Al2O3/MoS2 hybrid composite processed by powder metallurgy. *Alexandria Engineering Journal* 2016; 55(1): 13-17.
11. Safri SNA, Sultan MTH, Jawaid H et al. Impact behaviour of hybrid composites for structural applications: A review. *Composites Part B: Engineering* 2018; 133: 112-121.
12. Ramesh CS, Keshavamurthy R, Channabasappa BH. Microstructure and mechanical properties of Ni-P coated Si_3N_4 reinforced Al6061 composites. *Mater Sci Eng A* 2009; 502: 99-106.
13. Lashgari HR, Sufizadeh AR, Emamy M. The effect of strontium on the microstructure and wear properties of A356-10%B4C cast composites. *Mater Des* 2010; 31: 2187-2195.
14. Ramnath BV, Elanchezhian C, Jaivignesh M et al. Evaluation of mechanical properties of aluminium alloy-alumina-boron carbide metal matrix composites. *Materials & Design* 2014*;* 58: 332-338.
15. Pramanik, Sumit, et al. Metal Matrix Composites: Theory Techniques and Applications. *Composite Materials*. Springer, Berlin, Heidelberg, 2017; 369-411.
16. Sidhu SS, Kumar S, Batish A. Metal matrix composites for thermal management: a review. *Critical Reviews in Solid State and Materials Sciences* 2016; 41(2): 132-157.
17. Wan Yi, Takahashi J. Tensile properties and aspect ratio simulation of transversely isotropic discontinuous carbon fiber reinforced thermoplastics. *Composites Science and Technology* 2016; 137: 167-176.
18. Shirvanimoghaddam K, Hamim SU, Akbari MK et al. Carbon fiber reinforced metal matrix composites: Fabrication processes and properties. *Composites Part A: Applied Science and Manufacturing* 2017; 92: 70-96.
19. Jaswinder S. Fabrication characteristics and tribological behavior of Al/SiC/Gr hybrid aluminium matrix composites: A review." *Friction* 2016; 4(3): 191-207.
20. Jayalakshmi S, Gupta M. Metallic amorphous alloy reinforcements in light metal matrices. New York city: Springer International Publishing, 2015.
21. Hassan HA, Hellier AK, Crosky AK et al. Fracture toughness of cast and extruded Al6061/15% Al_2O_3p metal matrix composites. *Australian Journal of Mechanical Engineering* 2018; 1-9.
22. Wang W, Shi QY, Liu P et al. A novel way to produce bulk SiCp reinforced aluminium metal matrix composites by friction stir processing. *J Mater Process Technol* 2009; 209: 2099-2103.
23. Hsu CJ, Chang CY, Kao PW et al. Al-AL3Ti nanocomposite produced in situ by friction stir processing. *Acta Mater* 2006; 54: 5241-5249.
24. Yadav D, Ranjit R. Processing, microstructure and mechanical properties of nickel particles embedded aluminium matrix composites. *Mater Sci Eng A* 2011; 528: 1326-1333.
25. Ghaffari M, Tan PY, Oruc ME, et al. Effect of ball milling on the characteristics of nano structure SrFeO powder for photocatalytic degradation of methylene blue under visible light irradiation and its reaction kinetics. Catal Today. 2011; 161: 70-77.
26. Thareja P, Exploring qualte-k-nology for a breakthrough tomorrow (quality of, say, particulate technology knowledge). *Omni Science: A Multi-disciplinary Journal* 2013; 3(2): 12-26,
27. Bodukuri AK, Eswaraiah K, Rajendar K et al. Fabrication of Al-SiC-B4C metal matrix composite by powder metallurgy technique and evaluating mechanical properties. *Perspectives in Science* 2016; 8: 428-431.
28. Thareja P, Akhai S. Processing Parameters of Powder,

Aluminium-Fly Ash P/M Composites. *J Adv Res Manu Mat Sci Metall Engi* 2017; 4(3&4).
29. Jokhio MH, Muhammad IP, Mukhtiar AU. Manufacturing of aluminium composite material using stir casting process. *arXiv preprint arXiv:* 2016; 1604-01251.
30. Gladston JA, Dinaharan I, Selvam JDR et al. Production and characterization of rich husk ash particulate reinforced AA6061 aluminium alloy composites by compocasting. *Transactions of Nonferrous Metals Society of China* 2015; 25(3): 683-691.
31. Muraliraja R, et al. Development of alumina reinforced aluminium metal matrix composite with enhanced compressive strength through squeeze casting process. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications* 2019; 233(3): 307-314.
32. Woo DJ, Heer FC, Brewer LN et al. Synthesis of nanodiamond-reinforced aluminium metal matrix composites using cold-spray deposition. *Carbon* 2015; 86: 15-25.
33. Meignanamoorthy M, Ravichandran M. Synthesis of metal matrix composites via powder metallurgy route *Mechanics and Mechanical Engineering* 2018; 22(1): 65-75.
34. Kandpal BC, Singh H. Fabrication and characterisation of Al2O3/aluminium alloy 6061 composites fabricated by Stir casting. *Materials Today: Proceedings* 2017; 4(2): 2783-2792.
35. Mahdi AS, Mustapa MS, Hakim MA et al. Dry Sliding Wear Behavior of the Reinforced by Graphite Particle and Heat Treated of Recycled Aluminium AA6061 Based MMC Fabricated by Powder Metallurgy Method. *Key Engineering Materials*. *Trans Tech Publications Ltd* 2017; 740.
36. Akhlaghi F, Zare-Bidaki A. Influence of graphite content on the dry sliding and oil impregnated sliding wear behaviour of Al 2024-graphite composites produced by in situ powder metallurgy method. *Wear* 2009; 266(1&2): 37-45.
37. Liu YB, Hu JD, Cao ZY et al. Wear resistance of laser processed Al-Si graphite particle composites. *Wear* 1997; 206: 83-86.
38. Yilmaz O and Buytoz S. Abrasive wear of Al2O3 reinforced aluminium based MMCs'. *Compos Sci Technol* 2001; 61: 2381-2392.
39. Safiulla M, Ramesh CS, Ramachandra A. Tribological characteristics of extruded Al6061-5 wt. % SiC composites. In: Proceedings of the International Conference on Manufacturing (eds Anwarul H, Ahmed M, Karim ANM, et al.), Dhaka, 2002; 4-20.
40. Kok M, Ozdin K. Wear resistance of aluminium alloy and its composites reinforced by Al2O3 particles. *Journal of Material Processing and Technology* 2007; 183: 301-309.
41. Akhlaghi F, Bidaki AZ. Influence of graphite content on the dry sliding and oil impregnated sliding wear behaviour of Al-2024-graphite composites produced by in-situ powder metallurgy method. *Wear* 2009; 266: 37-45.
42. Sajjadi SA, Ezatpour HR, Torabi MP. Comparison of microstructure and mechanical properties of A356 aluminium alloy/Al_2O_3 composites fabricated by stir and compo casting processes. *Mater Des* 2012; 34: 106-111.
43. Kumar A, Lal S, Kumar S. Fabrication and characterization of A359/Al2O3 metal matrix composite using electromagnetic stir casting method. *J Mater Res Technol* 2013; 2: 250-254.
44. Kok M. Production and mechanical properties of Al2O3 particle reinforced 2024 aluminium alloy composites. *J Mater Process Technol* 2005; 161: 381-387.
45. Baradeswaran A, Elayaperumal A, Isaac RF. A statistical analysis of optimization of wear behaviour of Al/ Al_2O_3 Composites using Taguchi technique. *Procedia Eng* 2013; 64: 973-982.
46. Baradeswaran A, Perumal AE. Wear and mechanical characteristics of Al 7075/graphite composites. *Composites B* 2014; 56: 472-476.
47. Suresh S. Tribological Behavior of Al 7075 / SiC Metal Matrix Nano-Composite by Stir Casting Method. 2018.
48. Verma N. Review on Effect of Various Types of Reinforcement Particles on Mechanical Behavior of 6061 and 7075 Aluminium Alloy Matrix Co. *International Journal of Emerging Technologies in Engineering Research (IJETER)* 2017: 4-9.
49. Baradeswaran A, Perumal AE. Effect of Graphite on Tribological and Mechanical Properties of AA7075 Composites Effect of Graphite on Tribological and Mechanical Properties of AA7075 Composites. *Tribology Transaction* 2015: 1-6.
50. Beygi H, Sajjadi SA, Zebarjad SM. Microstructural Analysis and Mechanical Characterization of Aluminium Matrix Nanocomposites PhD Thesis View Project. *Materials Science & Engineering A* 2014; 607: 81-88.
51. Ruirui Wu, Yuan Z, Li Q. Microstructure and Mechanical Properties of 7075 Al Alloy Based Composites with Al_2O_3 Nanoparticles Microstructure and Mechanical Properties of 7075 Al Alloy Based Composites. *International Journal of Cast Metals Research* 2017; 0461: 1-4.
52. Prajapati AK, Omrani E, Menezes PL et al. Effect of Graphite Particles on Improving Tribological Properties Al-16Si-5Ni-5 Graphite Self-Lubricating Composite under Fully Flooded and Starved Lubrication Conditions for Transportation Applications. 2016.
53. Kulkarni R, Swan PM, Sonawane MG et al. Effect of

Graphite Addition on the Mechanical Properties of Stir Cast Particulate Aluminium Metal Matrix Composite Reinforced with Alumina and Silicon Carbide. 2001; 612: 163-68.

54. Gurcan AB, Baker. Wear behaviour of AA6061 alloy and its composites. *Wear* 1995; 188: 185-191.
55. Kumar, Ravinder and Suresh Dhiman. A Study of Sliding Wear Behaviours of Al-7075 Alloy and Al-7075 Hybrid Composite by Response Surface Methodology Analysis. *Materials and Design* 2013; 50: 351-59.
56. Ted GML, Tsao CYA. Tribological behaviour of self-lubricating aluminium/SiC/Gr hybrid composite synthesized by semisolid powder densification method. *Compos Sci Technol* 2000; 60: 65-74.
57. Ravindran P, Manisekar K, Narayanasamy P et al. Application of factorial techniques to study the wear of Al hybrid composites with graphite addition. *Mater Des* 2012; 39: 42-54.
58. Kannan C, Ramanujam R. *Journal of Advanced Research Comparative Study on the Mechanical and Microstructural Characterization of AA 7075 Nano and Hybrid Nanocomposites Produced by Stir and Squeeze Casting*. Cairo University. 2017.
59. Saheb, Dunia Abdul. Aluminium silicon carbide and aluminium graphite particulate composites. 2011; 6(10): 41-46.
60. Ahlatci H, Kocer T, Candan E et al. Wear behaviour of Al/ (Al_2O_3+SiC) Hybrid composites. *TribolInt* 2006; 39: 213-220.
61. Suresh P, Marimuthu K, Arunkumar G et al. Evaluation of parameters influencing surface roughness on turning of Al-SiC-Gr hybrid composites. *International Journal of Advanced Engineering Applications* 2013; 6(3): 38-43.
62. Radhika N, Subramanian R and Prasat SV. Tribological behaviour of aluminium/ alumina/ graphite hybrid metal matrix composite using Taguchi's techniques. *J Min Mater Charact Eng* 2011; 10: 427-443.
63. Ravindran P, Manisekar K, Narayanasamy P et al. Application of factorial techniques to study the wear of Al hybrid composites with graphite addition. *Mater Des* 2012; 39: 42-54.
64. Ravindran P, Manisekar K, Rathika P et al. Tribological properties of powder metallurgy processed aluminium self-lubricating hybrid composites with SiC additions. *Mater Des* 2013; 45: 561-570.
65. Unlu BS. Investigation of tribological and mechanical properties Al2O3-SiC reinforced Al composites manufactured by casting or P/M method. *Mater Des* 2008; 29: 2002-2008.
66. Suresha S and Sridhara BK. Wear characteristics of hybrid aluminium matrix composite reinforced with graphite and silicon carbide particulates. *Compos Sci Technol* 2010; 70: 1652-1659.
67. Suresha S, Sridhara BK. Effect of addition of graphite particulates on the wear behaviour in aluminium-silicon carbide-graphite composites. *Mater Des* 2010; 31: 1804-1812.
68. Altinkok N, Ozsert I, Findik F. Dry sliding wear behaviour of Al_2O_3/SiC particle reinforced aluminium based MMCs fabricated by stir casting method. *International Journal of Science and Advanced Technology* 2012.
69. Aruri, Devaraju, et al. "Wear and mechanical properties of 6061-T6 aluminium alloy surface hybrid composites [(SiC+ Gr) and (SiC+ Al_2O_3)] fabricated by friction stir processing. *Journal of Materials Research and Technology* 2013; 2(4): 362-369.
70. Alaneme KK, Olubambi PA. Fabrication characteristics and mechanical behaviour of rice husk ash-Alumina reinforced Al-Mg-Si alloy matrix hybrid composites. *journal of Materials Research and Technology* 2013; 2(1): 60-67.
71. Altinkok N, Koban A. The tensile behaviour and microstructure of Al_2O_3/SiCp reinforced aluminium based MMCs produced by stir casting process. *Int J Sci Adv Technol* 2012; 2: 78-86.
72. Devaraju A, Kumar A, Kumaraswamy A. Influence of reinforcements (SiC and Al_2O_3) and rotational speed on wear and mechanical properties of aluminium alloy 6061-T6 based surface hybrid composites produced via friction stir processing. *Mater Des* 2013; 51: 331-341.
73. Baradeswaran A, Vettivel SC, Perumal AE et al. Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C aluminium hybrid composites and graphite reinforced. *Mater Des* 2014; 63: 620-632.
74. Baradeswaran A and Perumal AE. Study on mechanical and wear properties of Al 7075/Al_2O_3/graphite hybrid composites. *Composites B* 2014; 56: 464-471.
75. Ahmadi A, Mohammad RT and Abbas N. Evaluation of microstructure and mechanical properties of Al/Al_2O_3/SiC hybrid composite fabricated by accumulative roll bonding process. *Mater Des* 2014; 53: 13-19.

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201903