RESEARCH REVIEW JOURNALS
Volume-04
Issue-05
May-2019

ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com[UGC Listed Journal]

Assessment of Mechanical and Tribological Properties of Aluminium Hybrid Metal Matrix Composites: A Review

*[1]Sneha.H.Dhoria, [2]V.Durga Prasada Rao & [3]K.Venkata Subbaiah

[1]*Asst. Professor, Dept. of Mechanical Engineering, R.V.R&JC college of Engineering, Chowdavaram (India)*
[2]*Professor, Dept. of Mechanical Engineering, S.R.K.R Engineering College, Bhimavaram (India)*
[3]*Professor, Dept. of Mechanical Engineering, Andhra University, Visakhapatnam (India)*

ARTICLE DETAILS

Article History
Published Online: 25 May 2019

Keywords
Aluminium metal matrix composites, Hybrid metal matrix composites, Tribological, Mechanical properties.

***Corresponding Author**
Email: snehadhoria[at]gmail.com

ABSTRACT

Advancements in technology have put an increasing demand on the composite materials, especially in the areas of dynamic structures. A Hybrid metal matrix composite(HMMC) is the composite material with at least three constituent parts, one being a metal necessarily and others may be different metals or materials called reinforcements. The reinforcements are added to get better stiffness, strength, and high strength to weight ratio and other mechanical properties. Among several types, Aluminium based hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the demands of advanced engineering applications. Of all the reinforcements used in the Aluminium metal matrix composites (AMC's), Silicon carbide and graphite has many better properties like increase in hardness, thermal conductivity and fracture energy. This paper aims at reviewing the literature available on various Aluminium based hybrid metal matrix composites used in present day applications. The effect of different hybrid reinforcements on AMC's in terms of their mechanical properties and tribological properties like tensile strength, strain, hardness, wear and fatigue was discussed.

1. Introduction

A Composite is the material made from two or more constituent materials with significantly different physical and chemical properties. When combined produce a material with characteristics different from individual components. There are two main categories of constituent materials namely Matrix and Reinforcement. Composites are of different types such as Metal matrix composite, Polymer composites and Ceramic composites. The common application of composites includes defence and aerospace structures [1]

The metal matrix composites are combination of two or more different materials including metal, inner metallic compound or next step dispersed phase of metal matrix [2]. To achieve optimum combination of properties, the morphology of constituents is controlled. It includes the properties of constituent's phase, its relative amount, dispersed geometry including particle shape and size along with orientation in matrix. The aim involved in designing the metal matrix composites is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement [3]. Its main purpose is to transfer and distribute the load to the reinforcement or fibers. This transfer of loads depends on the type of matrix, reinforcement and the fabrication technique [4]. Generally the matrix can be selected on the basis of oxidation and corrosion resistance or other properties. Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn, and Si are used as the matrix material, but Al, Ti, Mg are widely used. Hybrid composites are high tech and potential materials in the fields of automotive application due to their high strength, stiffness, low cost and weight. Hybridization is the process of incorporating two or more reinforcements in order to yield better properties than individual components. Hybrid composites primarily consists of one matrix and two or more reinforcements [7]. Modern industry is rapidly introducing different composites due to their unique properties such as low density and very light weight with high strength, hardness, stiffness, high fatigue strength and wear resistance in order to meet the challenge of liberalization and to maintain global competitiveness in the market [8]. Modern manufacturing engineers are also trying to introduce better properties in the composite by hybridizing usually available conventional composites at same phase.

2. Aluminium Hybrid MMCs

The Aluminium Matrix composites (AMCs) represent a class of MMCs having properties like low density, high stiffness and strength, superior wear resistance, controlled coefficient of thermal expansion, higher fatigue resistance and better stability at elevated temperatures [7]. Due to this, these composites are used for the design of wide range of components for advanced applications. Aluminium MMC's are widely used in aircraft, aerospace, automobiles and various other fields [8]. Aluminium comes next to steel, when it comes to automobile body frame with 5xxx and 6xxx series on the lead. AA6111, AA6009, AA5251 are currently used aluminium alloys in automobile industry while others are under development.

The reinforcement is usually done to improve properties like strength, stiffness, conductivity, etc of the base metal [9]. The reinforcements should be stable in the given working temperature and non reactive too. The final properties of the hybrid reinforcement depend on individual properties of

reinforcements selected and the matrix alloy [10]. The different ceramic materials that are generally used to reinforce aluminium alloys in MMCs are SiC, TiC, ZrC, TiB_2, ZrB_2, AlN, Si_3N_4, Al_2O_3, B_4C, SiO_2, Al_4Mo, Al_3Ti and Al_3Zr. These reinforcements influence micro structure, physical properties, tribological properties and other desirable properties of the composite [11]. Thus the hybrid composite is characterized by greater light weight, higher strength, higher stiffness, better toughness and desired wear resistance than those of conventional materials.

3. Review on AMCs

In this section, there is a review on the aluminium and its alloys as base metal and taking hybrid metal matrix composites. From the Table 1, it is clear that both the Mechanical and tribological properties of the hybrid composites were better than that of unreinforced alloy and in most of the cases the tribological properties like wear resistance of hybrid composites increased by using different reinforcements.

4. Conclusions

1. The current literature review revels that more extensive work has been done and reported to improve the properties of different aluminium based metal matrix composites by forming their composites being reinforced with various materials such as Al_2O_3,TiB_2,SiC,Graphite,B_4C, also by taking natural fibers like rice husk, fly ash, Eggshells etc.

2. Many researchers prepared the composites by using different methods like stir casting, Squeeze casting, Double stir casting, Powder metallurgy, Friction stir processing, Vortex method, ARB etc.

3. It is better to take two reinforcements instead of one, i.e., Hybrid metal matrix composites gives good properties of Mechanical and tribological, when compared to single reinforced or unreinforced composites.

4. Most of the work of fabrication of composites is done in stir casting and limited amount of work was observed in Squeeze process because stir casting process is easily available.

5. It is observed that among all the other reinforcements used in the Al MMC's Sic and graphite has better Mechanical and Tribological properties.

References

1. Nikhil V Nayak," Composite materials in aerospace applications", International Journal of Scientific and Research Publications sep, 4(9).
2. Vijaya Kumar Bhanot, Dharminder Singh, "Research work on Composite Epoxy Matrix & Epoxy Polyester reinforced material", International Journal of Engineering Research & Technology (2013);2(1).
3. AchuthaKini, Gowri Shankar M.C, Jayashree P.K, Raviraj Shetty and Sharma S.S, "Review on Effect of Silicon Carbide on Stir Cast Aluminium Metal Matrix Composites", International Journal of Current Engineering and Technology (2013); Vol:3,issue: 3,pp:1061-1071.
4. T. P. Rajan, R. M. Pillai and B. C. Pai. "Review Reinforcement Coatings and Interfaces in Aluminium Metal Matrix Composites', Journal of Material Science (1998), Vol: 33, issue: 14, pp:3491-3503.
5. Surappa MK. "Aluminium matrix composites: challenges and opportunities", Sadhana (2003), Vol:28 issue: (1–2),pp:319–334.
6. Davies G. Materials for Automobile bodies, Butterworth-Heinemann, Oxford, MA 01803, 2003; P. 90.
7. S.V.S. Narayana Murthy, B. Nageswara Rao and B.P. Kashyap. "Composites science and technology " (2003),pp: 63 119.
8. C.M. Anand Partheeban , M.Rajendran , S.C.Vettivel, S.Suresh , N.S.V.Moorthi, "Mechanical behavior and failure analysis using online acoustic emission on nano-graphite reinforced Al6061-10TiB_2 hybrid composite using powder metallurgy", Materials Science&EngineeringA632 (2015), pp: 1–13.
9. Dhanabal.S, Vetrivel.S.D, VimalRaja.M, "An Overview of hybrid metal matrix composites-characterization, directed applications and future scope:, IJSEAS (2015),vol: 1, issue :9,pp:344-350.
10. L. Krishnamurthy, B.K. Sridhara, D. Abdul Budan. "Comparative study on the machinability aspects of aluminium silicon carbide and aluminum graphite- silicon carbide hybrid composites. International Journal of Machining and machinability of Materials (2011);10(1/2),pp:137 -152.
11. M. Roy, B.Venkatataraman, V.V.Bhanuprasad, Y.R.Mahajan, Sundararajan, "The effect of particulate reinforcement on the sliding wear behavior of aluminum matrix composites Metallurgical transactions A23 (1992),pp: 2833- 2847.
12. V.Durga Prasada Rao, V.Navya Geethika, P.S.Krishnaveni "Multi-objective Optimization of Mechanical Properties of Aluminium 7075-Based Hybrid Metal Matrix Composite Using Genetic Algorithm", Advances in 3D printing and additive manufacturing technologies (2017),pp: 79-93.
13. K.R.Gopi, K.N.Mohandas, H.N Reddappa, M.R.Ramesh. "Characterization of as cast and heat treated Aluminium 6061/zircon sand/graphite particulate hybrid composites", IJEAT (2013), Vol: 2,issue: 5,pp:340-344.
14. Gurwinder Singh & Charanjeet Singh Kalra "Fabrication and characterization of al-based hybrid composite reinforced with SiC, Al_2O_3 and C particles by squeeze casting" (2014), Vol.3,pp:1-9.
15. K.Umakanth, K.Palani kumar, S.T.Selvamani, "Analysis of dry sliding wear behaviour of Al6061/Sic/Al_2O_3 hybrid metal matrix composites", Composites part B. Engineering (2013),Vol-53,pp:159-168.
16. 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", Material Design (2014), Vol: 53, pp:13–19.
17. Prasad DS and Shoba C. "Hybrid composites – a better choice for high wear resistant materials", Journal of Materials Research Technology 2014; 3: 172–178.
18. Vinod kumar, Phool Kumar, Surender Sharma," Wear characterization of Aluminium/Sic/Al_2o_3 hybrid metal matrix composite using taguchi method", IJIRD (2014), Vol: 3, Issue: 1, pp:34-40.

19. R.Balamurugan, N.Sethuraman, S.Sudagar, A.Arun," Wear behaviour of Hybrid Al+Sic+Al_2o_3 metal matrix composites", IJETAE (2015), Vol: 5,issue :12,pp:199-205.
20. Kamaal Haider, Md. Azad Alam, Amit Redhewal,Vishal Saxena, "Investigation of Mechanical Properties of Aluminium Based Metal Matrix Composites reinforced With Sic & $Al_2O_{3'}$ IJERA (2015),Vol: 5,Issue :9, pp: 63-69.
21. Bijay Kumar Show, Dipak Kumar Mondal and JoydeepMaity. "Dry Sliding Wear behaviour of Aluminium-Based Metal Matrix Composites with Single (Al_2O_3) and Hybrid (Al_2O_3 + SiC) Reinforcements", Metallurgy. Microstructure. Anal.(2014), Vol: 3,pp:11-29.
22. Sri Priya R, Yogeshwaran R, Syed Mohammed K, Bharathvaj S, Dr.M. Shanmugaraja, "Investigation on Mechanical Properties of Aluminium 6061 reinforced with Sic and Al_2O_3", International Conference on Explorations and Innovations in Engineering & Technology (2016), pp: 49-53.
23. Mohammed Naveed, A.R.Anwar Khan," Ultimate tensile strength of heat treated hybrid metal matrix composites", International journals of science and research (2015), Vol: 4, issue :9,pp:146-151.
24. Y. Mazaheri n, M.Meratian, R.Emadi, A.R.Najarian "Comparison of micro structural and mechanical properties of Al–TiC, Al–B_4C and Al–TiC-B_4C composites prepared by casting techniques", Materials Science & Engineering A 560 2013,278–287.
25. Poovazhagan, L, Kalaichelvan, Rajadurai, A, & Senthilvelan. V. " Characterization of Hybrid Silicon Carbide and Boron Carbide Nano particles-Reinforced Aluminum Alloy Composites", Proceedia Engineering (2013), Vol:64, pp: 681-689.
26. Anil Kumar Bodukuri, K. Eswaraiah, Katla Rajendar a, V. Sampatha, "Fabrication of Al—SiC—B_4C metal matrix composite by powder metallurgy technique and evaluating mechanical properties", Perspectives in Science (2016), Vol: 8, pp: 428—431.
27. Vijaya M, Kolla Srinivas, Sneha H Dhoria, "Synthesis, Characterization and Deformation Studies of Blast Furnace Slag Particles Reinforced Aa2024 Composite', Journal of Thin Films, Coating Science Technology and Application. 2016;3(3).
28. S.Thirumalai Kumaran, M.Uthayakumar, S.Aravindan. "Analysis of dry sliding friction and wear behaviour of AA6351–SiC–B_4C composites using grey relational analysis", Taylor and Francis, Tribology- Materials, surfaces and interfaces (2014), Vol:8, issue: 4,pp:187-193.
29. AlptekinKisasoz, KeremAltugGuler, Ahmet Karaaslan. 'Infiltration of A6063 aluminium alloy into SiC–B_4C hybrid preforms using vacuum assisted block mould investment casting technique",Transactions of Nonferrous Metals Society of China (2012); Vol: 22,pp: 1563-1567.
30. Uvaraja V.C, Natrajan N."Optimization of friction and wear behavior in hybrid metal matrix composites using Taguchi technique", Journal of Minerals and Materials Characterization and Engineering (2012), Vol:11, pp:757-768.
31. Prasad DS, Shoba C and Ramanaiah N, "Investigations on mechanical properties of aluminum hybrid composites", Journal of Material Research Technology (2014), pp: 79–85.
32. V.L. Kingston, John Prabhakar, "A study on mechanical and machinability characteristic of HMMCs", IJERA (2014),pp: 67-70.
33. Basavaraj Mathpathi, Bharat S Kodli."A Study on Mechanical Properties of Aluminum, Rice Husk and Silicon Carbide Matrix Composites', International Journal for Scientific Research & Development (2014) Vol: 2, Issue: 8, pp:13-14.
34. Victor Sunday Aigbodion, "Development of Al-Si-Fe/Rice husk ash particulate composites synthesis by double stir casting method", Usak University Journal of Material Sciences (2012), 2:187-197.
35. Dora Siva Prasad, Chintada Shoba, "Experimental evaluation onto the damping behavior of Al/SiC/RHA hybrid composites", Journal of Materials research and technology (2015), pp: 1-8.
36. K.K. Alanemea, T.M. Adewalea, "Influence of Rice Husk Ash – Silicon Carbide Weight Ratios on the Mechanical behaviour of Al-Mg-Si Alloy Matrix Hybrid Composite", Tribology in Industry (2013), Vol: 35,issue: 2,pp:163-172.
37. Kenneth KanayoAlaneme, TolulopeMoyosoreAdewale, Peter ApataOlubambi, "Corrosion and wear behaviour of Al–Mg–Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide),Journal of material research technology (2014); Vol: 14 3 issue : 1, pp:9–16.
38. M. Laad, V. S. Jatti, S. Yadav," Comparative Study between SiC Reinforced Al 64430 Metal Matrix Composites and RHA reinforced Al 64430 Metal Matrix Composites", Advanced Materials Research (2015), 1119, pp: 234-238.
39. Baradeswaran, A. and A. ElayaPerumal," Study on Mechanical and Wear Properties of Al 7075/Al_2O_3/Graphite Hybrid Composites",Composites Part B: Engineering (2014), Vol: 56, pp: 464- 471.
40. DevarajuAruri, Kumar Adepu, KumaraswamyAdepu and KotiveerachariBazavada, "Wear and Mechanical Properties of 6061-T6 Aluminum Alloy Surface Hybrid Composites [(SiC + Gr) and (Sic + Al_2O_3)] fabricated by Friction Stir Processing" ,Journal of Materials Research and Technology (2013); Vol: 2,issue: 4, pp:362- 369.
41. Sameer MD, AK Birru," Experimental investigations on Mechanical behaviour of Al_2O_3 and Graphite reinforced Al Hybrid metal composites by stir casting process", International Journal of Scientific & Engineering Research (2016); Vol: 7, issue: 6, pp:37-42.
42. Sudindra.S, C. Anil kumar, "Studies on Al6061/Al_2O_3 and graphite Hybrid metal matrix composites", IJMMSE (2013), Vol: 3, pp:35-42.
43. MadevaNagaral, V.Auradi, Ravi shankar M.K. "Mechanical Behaviour of Aluminum 6061 reinforced with Al_2O_3 and graphite particulate hybrid metal matrix composites", IJERT (2013), Vol: 1, Issue: 2, pp:193-198.
44. Gheorghe, Gabriela, Mihai "Studies regarding Technological Properties of Al/Al_2O_3/Graphite Hybrid Composites", U. P. B. Sci. Bull., Series B (2013), Vol: 75(2),pp:117-125.
45. V.N.Gaitonde, S.R.Karnik, M.S.Jayaprakash " Some studies of Wear and Corrosion Properties of Al5083/Al_2O_3/Graphite Hybrid Composites", Journal of Minerals and Materials Characterization and Engineering (2012), Vol:11, pp:695-703.
46. Ravindran P, Manisekar K, Vinoth Kumar S, Rathika P. "Investigation of microstructure and mechanical properties of aluminum hybrid nano-composites with the additions of solid lubricant", Material Design (2013), vol: 51 pp: 448–456.
47. 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', Composites Science and Technology 60(2000), pp: 65-74.
48. M. Asif, K. Chandra, P. S. Misra," Development of Aluminium based Hybrid Metal Matrix Composites for Heavy Duty Applications", Journal of Minerals & Materials Characterization& Engineering 2011; 10(14): 1337-1344.
49. Yahya Altunpak, Mustafa Ay, Serdar Aslan, "Drilling of a Hybrid Al/SiC/Gr metal matrix composites', International journal of advanced manufacturing technology (2010), Vol: 49, pp: 871-877.
50. FarshadAkhlaghi, S. Madhavi, "Effect of the SiC Content on the Tribological Properties of Hybrid Al/Gr./SiC Composites processed by In Situ Powder Metallurgy (IPM) Method",

Advanced Materials Research (2011), 264-265, pp: 1878-1886.
51. M. V. Achutha, B. K. Sridhara, Abdul Budan ,"Fatigue life Estimation of Hybrid aluminium matrix composites", International Journal on Design and Manufacturing Technologies 2008; 2; 14-21.
52. Satyappa Basavarajappa, Govindarajulu Chandramohan. "Dry Sliding wear behaviour of Hybrid Metal Matrix Composites", Material Science 2005; Vol: 11, issue: 30, 253-257.
53. Yanamandala Raghuram Chowdary, C.Yuvaraj, K.Prahlada Rao, B.Durgaprasad, "Evaluation of Mechanical properties of Al/SiC-Graphite Hybrid metal Matrix composites", International Journal of Advanced Trends in Computer Science and Engineering 2013; 2(6):286-289.
54. B. M. Viswanatha, M. Prasanna Kumar, S. Basavarajappa, T.S.Kiran, "Mechanical Property Evaluation of A356/Sicp/Gr Metal Matrix Composites",Journal of Engineering Science and Technology (2013), Vol: 8, issue: 6, pp:754 – 763.
55. Mahendra Boopathi.M, K.P.Arulshri, N.Iyandurai, "Evaluation of Mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and Flyash hybrid metal matrix composites", American journal of Applied Sciences 2013; 10(3):219-229.
56. Ahlatci H, Kocer T, Candan E."Wear behavior of Al/ (Al_2O_3+SiC) Hybrid composites", TribolInt 2006; 39:213–220.
57. Radhika N, Subramanian R and Prasad SV, "Tribological behaviour of aluminium/alumina/graphite hybrid metal matrix composite using Taguchi's techniques", Journal of Mineral Materials Characterization Engineering (2011), vol: 10 pp: 427–443.
58. Soleymani S, Abdollah ZA and Alidokht SA. "Microstructural and tribological properties of Al 5083 based surface hybrid composite produced by friction stir processing",. Wear (2012), Vol: 278–279, pp: 41–47.
59. Ravindran P, Manisekar K, Rathika P ,"Tribological properties of powder metallurgy – processed aluminium self-lubricating hybrid composites with SiC additions', Materials Design (2013), 45, pp: 561–570.
60. Sneha. H. Dhoria, Vijaya M, SanthiPriya P, T Yamini. "Investigation of Mechanical Properties of Al356 Metal Matrix Composites. Trends in Mechanical Engineering & Technology", 2016; 6(2)
61. Alidokht SA, Abdollah ZA, Soleymani.S, "Microstructure and tribological performance of an aluminium alloy based hybrid composite produced by friction stir processing", Material Design (2011), vol: 32, pp: 2727–2733.
62. Altinkok N and Koban A, "The tensile behavior and microstructure of Al_2O_3/SiCp reinforced aluminum based MMCs produced by stir casting process",International journal of Science and advanced technology (2012)Vol: 2, pp: 78–86.
63. Uvaraja VC and Natarajan N. "Optimization of friction and wear behavior in hybrid metal matrix composite by taguchi technique",Journal of Mineral Material Characterization Engineering(2012), Vol: 11,pp: 757–768.
64. Alaneme KK and Olubambi PA "Corrosion and wear behaviour of rice husk ash—Alumina reinforced Al–Mg–Si alloy matrix hybrid composites", Journal of Mater Research Technology (2013), Vol: 2, pp:188–194.
65. Elango G and Raghunath BK "Tribological behavior of hybrid (LM25Al + SiC+ TiO_2) metal matrix composites", Procedia Engineering (2013), 64, pp: 671–680.
66. Mazahery Y, Maratian M, Emadi R ," Comparison of microstructural and mechanical properties of Al-TiC,Al-B_4C, Al-TiC-B_4C composites prepared by casting technique". Mater Science Engineering A (2013), 560: pp: 278–287.
67. Uthayakumar M, Aravindan S and Rajkumar K. "Wear performance of Al–SiC–B_4C hybrid composites under dry sliding conditions", Material Design(2013), Vol: 47, pp: 456–464.
68. David RSJ, Robinson SDS and Dinaharan I" Synthesis and characterization of Al6061-Flyashp-SiCp composite by stir casting and compo-casting",Energy Procedia(2013), Vol: 34,pp: 637–646.
69. B. Vijaya Ramnath , C. Elanchezhian , M. Jaivignesh , S. Rajesh , C. Parswajinan , A. Siddique Ahmed Ghias. "Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites", Materials Design (2014), Vol: 58, PP: 332–338.
70. Baradeswaran A, Vettivel SC, Perumal AE, N. Selvakumar d, R. Franklin Issac. "Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B_4C aluminium hybrid composites and graphite reinforced", Materials Design (2014), Vol: 63, pp: 620–632.
71. Reihanian M, Hadadian FK and Paydar MH. "Fabrication of Al–2 vol% Al_2O_3/SiC hybrid composite via accumulative roll bonding (ARB): an investigation of the microstructure and mechanical properties", Material Science Engineering A (2014), 607, pp:188–196.
72. Suresh S, Moorthi NSV, Vettivel SC, G.r.jinu, "Effect of graphite addition on mechanical behavior of Al6061/TiB2 hybrid composite using acoustic emission, Material Science Engineering A (2014), Vol:612, pp: 16–27.
73. Anand Kumar, Manas Mohan mahapatra, Pradeep Kumar. "Fabrication and characterization of Mechanical properties of Al-4.5%Cu/10TiC composite by insitu method",Journal of minerals and Materials characterization and Engineering (2012),1075-1080.
74. Alaneme KK, Adewale TM and Olubambi PA., "Corrosion and wear behavior of Al–Mg–Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide", Journal of Material Research Technology (2014); 3: 9–16.
75. H.K.Shivanand, Yogananda.A.," Development and Characterization of corrosion properties of Aluminium 8011 Hybrid Metal matrix composites", IRF International Conference, (April 2015), 8-10.
76. Radhika N, Balaji T. V, Palaniappan. S. " Studies on Mechanical Properties and Tribological behaviour of Lm25/Sic/Al_2O_3 Composites", Journal of Engineering Science and Technology (2015);10(2):pp:134–144.

Appendix

Table 1: Literature review on aluminium Hybrid metal matrix composite

S No	Matrix	Reinforcement	Manufacturing process	Mechanical properties	Tribological properties	Result	Ref
1	Al7075	SiC,TiO_2	Stir casting	Hardness, Impact, Tensile	----	Hardness increases when compared to unreinforced.	12
2	Al6061	Zircon sand, graphite	Stir casting	Hardness	Wear	When compared to untreated composites, the heat treated composites showed reasonable improvement in their properties.	13
3	Pure Al	SiC,Al_2O_3,C	Squeeze casting	Hardness, Impact test	-----	It is found that the results from squeeze formed Al, reinforced with SiC/Al_2O_3/C particle is having superior properties in comparison of impact strength and hardness.	14
4	Al6061	SiC,Al_2O_3	Stir casting	-----	Wear	The results indicated that the wear resistance of the 15% hybrid composite is better than that of the 5% composite. The results also concluded that the applied load has the highest influence on the wear rate followed by sliding speed and sliding distance.	15, 18
5	Al	Al_2O_3,SiC	Anodizing and Accumulative roll bonding	Tensile strength,% elongation	---	Tensile strength was 3.1 times higher than that of pure aluminium matrix while tensile strength and % elongation improved with increased number of ARB cycles.	16
6	A356.2	RHA,SiC	Vortex method	--	Wear	Hybrid composites had better wear resistance than that of pure aluminum matrix and it increased with increase in the content of reinforcement.	17
7	Al	Sic,Al_2O_3	Powder metallurgy	Hardness	Wear	The incorporation of SiC and Al_2O_3 particles into the Al improves the sliding wear resistance as compared to the unreinforced alloy. And the hardness of the composite is also increased when compared to unreinforced alloy.	19
8	Al6061	Sic,Al_2O_3	Stir casting	Hardness, Tensile, Impact strength	-----	Density found increasing with increased SiC and Al_2O_3 content. With increase in ceramic particulates, the hardness of the SiC & Al_2O_3 filled Al6061 alloy composites also increases.	20
9	Al6351	SiC,Al_2O_3	Stir casting	Hardness	Wear	The overall wear rate increases with load in all the specimens. However, at higher loads the breakdown of (SiC+Al_2O_3) particle clusters results in a high wear rate in the hybrid composite.	21
10	Al6061	Sic,Al_2O_3	Stir casting	Hardness, Tensile and Impact test		Hardness, Tensile, yield strength of hybrid composites increases by increasing the reinforcements when compared to base alloy.	22
11	Al6061	Flyash, SiC	Stir casting	Hardness, tensile strength	---	The macro hardness and tensile strength of the composite increased with increase in weight percent of the SiC particles.	23
12	Al	Tic,B_4C	Squeeze casting	Hardness, tensile	Wear	The maximum hardness occurs at Al–5%TiC–5%B_4C composite, maximum yield and tensile strength had belonged to Al–10%B_4C composite and maximum elongation had belonged to Al–10%TiC composite. The wear properties of composites revealed the better behavior for Al–B_4C composite.	24
13	Al6061	SiC,B_4C	Ultrasonic cavitation based solidification process	Hardness, Tensile and Impact test	----	Hardness and tensile strength of the hybrid composites increased quite significantly while the ductility and impact strength reduced marginally when compared to unreinforced alloy.	25
14	Al	Sic,B_4C	Powder Metallurgy	Hardness	---	The increase in percentage of B_4C, the micro hardness of the metal matrix composite has increased significantly.	26
15	Al2024	Blast furnace slag	Stir casting	Hardness, Compressive strength		It is found that hardness value 5% fine particles of slag is more when compared to the base metal and 5% coarse particles of slag is more. Compressive properties of synthesized. The compressive strength increases with increase in size of slag particle and then decreases.	27
16	Al6351	SiC,B_4C	Stir casting	----	Wear	It is observed that the dry sliding friction and wear behaviour of the composites are influenced by the applied load, sliding velocity and weight % of B_4C.	28

17	Al6063	SiC,B_4C	Vacuum assisted mould investment	Hardness, Image analysis	--	As increase in percentage of B_4C the micro hardness of the metal matrix composite has increased significantly.	29
18	Al7075	SiC,B_4C	Liquid metallurgy	Hardness	Wear	The wear rate is dominated by the order of percentage of reinforcement, applied load, sliding speed, and sliding time. ANOVA test concluded that as percentage of reinforcement increases the wear rate also decreases significantly.	30
19	A-356.2	RHA,SiC	Double stir casting	Hardness, UTS, and Yield strength	---	The hardness, UTS and yield strength was better than that of pure matrix and single-reinforced composites.	31
20	Al	Sic,B_4C	Stir Casting	Hardness, Impact Tensile, Compression	---	It is found that the strain value increases proportionally as the stress value increases for a maximum limit and further as the stress increases the strain drops.	32
21	Al	SiC, Rice husk	Liquid metallurgical	Tensile, Impact hardness	---	While increasing Rice husk content we get higher tensile strength. By increasing the Sic we get higher impact strength and hardness of the hybrid composite.	33
22	Al	Si-Fe, Rice husk	Double stir casting	Hardness, Tensile Strength, Yield Strength	---	By keeping Sic and iron constant and varying the rice husk particles to Al-Si-Fe alloy increases both the yield strength, Ultimate tensile strength and hardness values up to a maximum values.	34
23	A356.2	SiC, Rice husk	Two stage stir casting	Density	--	Dislocation density results from the thermal mismatch between the reinforcement and the matrix, the porosity of composites has a great influence on the damping capacity of hybrid composites.	35
24	Al-Mg-Si	Rice husk ash, SiC	Two step stir process	Porosity, Density measurement , tensile	Fracture toughness	The results show that the composites were of good quality as the estimated porosity values are less than 2.5% in all grades produced.	36
25	Al-Mg-Si	RHA, SiC	Double stir casting	--	Corrosion, Wear	The effect of RHA/SiC weight ratio on the corrosion behaviour of the composites in 3.5% NaCl solution was not consistent for the different weight percent of reinforcements used in developing the Al–Mg–Si based composites. In most cases the use of hybrid reinforcement of RHA and SiC resulted in improved corrosion resistance of the composites in 3.5% NaCl solution.	37
26	Al6440	SiC, RHA	Liquid metallurgy	Hardness, Tensile strength & Structural properties	---	RHA can be used as reinforcement material to synthesize light weight composites with increased hardness, tensile strength, Young's modulus for various industrial applications.	38
27	Al7075	Al_2O_3, Graphite	Liquid Metallurgy	Hardness, Tensile strength, Flexural strength, compression strength	Wear	By increasing the reinforcement of ceramic phase, hardness, Tensile strength, Flexural strength and compressive strength also increases. The wear properties of the hybrid composites containing graphite exhibited the superior wear-resistance properties.	39
28	Al6061	(SiC+Gr) ($SiC+Al_2O_3$)	Friction stir processing	Hardness, Tensile	Wear	Hardness and wear resistance of hybrid composites were better than that of base matrix but better result obtained in SiC + Al_2O_3-reinforced hybrid composites.	40
29	Al6063	Al_2O_3, Graphite	Stir casting	Hardness, Tensile strength	--	Tensile strength, hardness increases	41
30	Al6061	Al_2O_3, Graphite	Stir casting	Hardness	--	By addition of Al_2O_3 the hardness increases while addition of graphite particles with varying combinations ductility decreases.	42
31	Al6061	Al_2O_3, Graphite	Stir casting	Hardness, Tensile strength	--	It is observed that the hardness of Al6061/Al_2O_3/Graphite hybrid composites decreased by increasing the content of graphite particulates.	43
32	Al	Al_2O_3,Graphite	Powder Metallurgy	Apparent, Tap densities	---	With increasing the graphite content in the mixture and milling time the apparent and tap density increases.	44
33	Al5083	Al_2O_3, Graphite	Stir casting	Hardness		By increasing the hard reinforcements in the hybrid composites the micro hardness also	45

						increases.	
34	Al2024	SiC, Graphite	Powder Metallurgy	Hardness	Wear	The composite with Al2024 and 5wt. % SiC and 10wt% Gr. shows the greatest improvement by having the highest strength and wear resistance.	46
35	Al6061	SiC, Graphite	Semi solid powder densification	Hardness, Fracture energy	Wear	Fracture energy decreases monotonously as the amount of graphite addition increases. Wear rate of the counterpart increases as the amount of graphite addition in the composites increases up to 8% Gr addition.	47
36	Al	SiC, Graphite, Sb_2S_3	Powder metallurgy	-	Wear	Incorporation of graphite particles in the aluminium matrix as a second reinforcement decreases the wear rates of the composite compared to SiCp reinforced composite.	48
37	Al (LM2)	SiC, Graphite	Vortex method	-----	Surface finish	Surface finish is poor at drilling of Al/20%SiC/10%Gr composite compared to Al/20%SiC/5%Gr composite	49
38	Al6061	SiC, Graphite	Powder metallurgy	Hardness, Density	Wear	While 9 vol.% graphite addition to Al6061 powder resulted in deterioration of the wear properties of the sintered composite as compared to the base alloy, the wear rate of Al/9%Gr/20%SiC hybrid composite was 10 times lower than of the unreinforced alloy.	50
39	Al6061 (LM5)	SiC, Gr	Gravity Die casting	Hardness, Tensile strength, Ultimate tensile strength	Fatigue	Mechanical properties were observed. The fatigue resistance of Hybrid Al-SiC-Gr composite is superior to that of the matrix alloy.	51
40	Al2219	SiC, Graphite	Liquid metallurgy	----	Wear	The wear rate has been increased with the increasing load and decreased with increasing speed up to 4.6m/s and then increased. The incorporation of graphite particles in the Al matrix as a second reinforcement decreases the wear rate of the composite when compared to SiC reinforced composite.	52
41	Al6061	SiC, Graphite	Pressure die casting	Ultimate Tensile strength	---	An increase in the percentage of graphite &SiC reinforcements in aluminium alloy increases the ultimate tensile strength and young's modulus.	53
42	A356	Sic, Graphite	Liquid metallurgy	Hardness, tensile strength	--	The hardness of composites increased significantly with addition of SiCp, while maximum hardness was obtained for 9% of SiCp. The addition of low weight percentage of SiCp to A356 leads to increase in tensile strength and decrease in percentage elongation.	54
43	AA2024	SiC, Flyash	Two step stir casting	Density, Hardness, Tensile strength	---	Density of composites decreases with increasing in reinforcement. Al-SiC-fly ash composites show better performance when compared to the Al-SiC and Al-flyash.	55
44	Al-Mg	SiC,Al_2O_3	Pressure infiltration	Hardness, Compression strength, Impact	Wear	Dry sliding wear improved with increased amount of magnesium in the matrix which also resulted in increased mechanical properties	56
45	Al-Si-10Mg	Al_2O_3,Gr.	Stir Casting	--	Wear	Wear resistance was better than that single reinforced composites and matrix.	57
46	Al5083	SiC,MoS_2	FSP		Wear	Wear resistance was better than that single reinforced composites and matrix.	58
47	Al	Al_2O_3,SiC	Stir casting	Hardness	Wear	Both the hardness and wear properties were improved as compared to pure aluminum matrix and the wear resistance of hybrid composite was better than that of single-reinforced composites	59
48	Al356	SiC,Gr	Stir casting	Hardness, Tensile	-	Hardness of alloy increases with increase in reinforcement.	60
49	A356	SiC,MoS_2	Friction stir processing	Hardness	Wear	Hybrid composite had better wear resistance as compared to that of cast alloy and had higher hardness compared to base metal, the incorporation of MoS_2 reinforcement in A356-SiC composite as a second reinforcement further increased the wear resistance of composites.	61
50	A332	SiC,Al_2O_3	Stir casting	Tensile strength	---	Tensile strength of hybrid composite increased as compared to pure matrix.	62
51	AA7075	SiC,B_4C	Stir casting	--	Wear	Wear resistance of hybrid composite was better	63

						than that if the pure matrix.	
52	Al-Mg-Si	RHA, Al_2O_3	Double stir casting	--	Wear	Wear resistance of Al_2O_3-reinforced composite increased with increase in RHA content.	64
53	LM25	SiC,TiO_2	Stir casting	Hardness, Tensile strength	Wear	Hardness, strength and wear resistance were better than that of base matrix and increased by increasing the amount of both reinforcement or keeping one constant and increasing the other.	65
54	Al	TiC, B_4C	Stir casting	Hardness	--	Hybrid composites had better hardness than single reinforced composites.	66
55	AA1100	SIC,B_4C	Stir casting	--	Wear	Wear resistance was better than that of base matrix.	67
56	AA6061	FA,SiC	Stir casting	Tensile strength, Hardness	--	Tensile strength and hardness increased with increase in volume fraction of SiC particulates with constant volume fraction of FA.	68
57	LM25	Al_2O_3.,B_4C	Stir casting	Hardness	--	Hardness was better than that pure aluminum matrix and increased with increased content of reinforcement.	69
58	AA6061 and AA7075	B_4C,Gr	Stir casting	Hardness	Wear	Hardness and wear resistance was better than that of pure metal in both hybrid composite, but hardness and ductility was better in case of AA7075 while wear resistance was better in AA6061 case.	70
59	AA1050	Al_2O_3,Sic	Accumulative roll bonding	Hardness, tensile Strength	--	Hardness and tensile strength was better than that of pure matrix and increased with increasing the ARB cycle	71
60	AA6061	TiB_2,Gr	Stir casting	Hardness, Tensile strength	---	Hardness and tensile strength was better than that of pure matrix and increased with increasing the content of reinforcement.	72
61	Al	Cu,Ti	Insitu process	Hardness, yield ultimate strength	--	Hardness, Yield strength, tensile strength increases.	73
62	Al-Mg-Si	RHA+SiC	Double Stir casting	--	Wear	Use of RHA with SiC has a significant effect in reducing the wear rates of hybrid composite	74
63	Al8011	Fly ash, E-Glass	Stir casting		Corrosion	The composite specimen showed better corrosion resistance than that the unreinforced matrix alloy.	75
64	LM25	SiC, Al_2O_3	Liquid processing technique	Tensile, hardness	Wear	As the reinforcement of Al_2O_3 and SiC content increases, the depth and number of grooves on the surface of the pin decreases, thus increasing the wear resistance.	76

