EFFECT OF REINFORCEMENT AND PROCESS ON FATIGUE AND FRACTURE OF AMCs-A REVIEW

***K. H. Sanath kumar*[1], *G.S.Shiva Shankar* [2]**

[1]*Research scholar, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India.*
[2]*Professor, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India.*

Abstract: Aluminium metal matrix nano composites are very promising materials featuring for physical and mechanical properties very different from those of the metal matrix composites. This paper presents the effect of addition on different reinforcements in aluminium alloy to improve fatigue strength and fracture toughness and also discussed different methods of processing aluminium metal matrix composites highlighting their merits and demerits. The addition of reinforcement into metallic matrix composites improves the wear resistance, creep, fracture and fatigue properties compare to conventional engineering materials.

Index Terms - Aluminum metal matrix composites (AMCs), Reinforcement, Mechanical properties and stir casting.

I. INTRODUCTION

MMC (Metal matrix composites) are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, etc. Aluminium and its alloys have attracted most attention as base metal in metal matrix composites [7]. Boron Carbide is one of hardest known elements. It has high elastic modulus and fracture toughness. The addition of Boron Carbide (B4C) in Al matrix increases the hardness. Most of study stated in literature has been dedicated to Al composite like A359, 6061, 6063, 7075, A357 [1-3]. Research work on Al2219 as hybrid composite is less. However, Al2219 made its name in applications like contact parts of airframe and fuel tank of rockets [4-6]. The primary objective of this study is developing hybrid aluminium metal matrix composite using Al2219 reinforced with Boron Carbide (B4C) and Molybdenum Disulphide (MoS2), Silicon carbide, Aluminium oxide, zircon, and Fly ash.

II.PROCESSING OF ALUMINIUM METAL MATRICS COMPOSITES

Primary processes for manufacturing of AMCs at industrial scale can be classified into two main groups

A. Solid state processes:

Powder metallurgy

The powder metallurgy press and sinter process generally consists of three basic steps: powder blending (pulverisation), die compaction, and sintering. Compaction is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at atmospheric pressure and under carefully controlled atmosphere composition. Optional secondary processing such as coining or heat treatment often follows to obtain special properties or enhanced precision. The tooling and equipments require for powder metallurgy are very expensive, therefore becomes main issue with low production volume. It's difficult to produce large and complex shaped parts with powder metallurgy. [15]

Fatigue is an important design consideration for PM parts subject to cyclic stresses. In general, the fatigue strength of press-and-sinter aluminium PM parts is about half that of wrought alloys with similar composition (ASM, 1998). Because of the involvement of pores, the fatigue of a sintered aluminium alloy may differ appreciably from that of a cast or wrought alloy. At present experimental data on the fatigue of sintered aluminium alloys are still very limited (Grayson et al., 2006) [15]

Centrifugal casting

It is a casting technique that is typically used to cast thin-walled cylinders. It is used to cast such materials as metal, glass, and concrete. It is noted for the high quality of the results attainable, particularly for precise control of their metallurgy and crystal structure. In the centrifugal casting process, molten metal is poured into a spinning die. The die can be spinning either on a vertical or horizontal axis depending on the configuration of the desired part. Ring. And cylinder type shapes are cast vertically; tubular shapes are made with the horizontal centrifugal process.

Aakanksha suryawanshi et, al., [14] concludes the defects in centrifugal casting decreases the strength and quality of product and avoiding defects is one of the major problem in centrifugal casting.

A. Liquid state processes:

Liquid state processes include stir casting, compo casting and squeeze casting spray Casting and in situ (reactive) processing, and ultrasonic assisted casting [8].

Squeeze casting:

Squeeze casting is the combination of the casting and forging processes that can be done with help of high pressure when it is applied during melt solidification. Applying pressure on the solidification of molten metal could change melting point of alloys which enhances the solidification rate. Moreover it refines the micro and macrostructure; it is helpful to minimize the gas and shrinkage porosities of the castings.

Krishna P et, al.,[16] concludes One of the greatest drawbacks that inventors of squeeze casting have encountered is the configuration of re-entrant cavities and internal passages that use the core. One of the possible solutions brought up was creating a core from conventional sand coring. Although this method seemed like a valid solution, the high temperatures from molten metal easily penetrated the core made from sand. Along the way, other inventors have also come up with different methods such as using traditional salt cores, but like sand coring, they are equally, if not more susceptible to stress and cracking.

Manjunath Patel GC et,al.,concludes Although much research efforts reported in the available literatures, still the process industries and researchers are not getting powerful modelling tools to improve the squeeze cast components. The use of statistical tools establishes the input-output relationship and provides the complete insight of the process, but fails to meet specific industry requirements.

Stir casting:

Siddesh Kumar N G et, al., [18] shows Metal matrix hybrid composites are fabricated by using liquid metallurgy technique (stir casting). The resistance furnace used for casting purpose. Monolithic Al2219 is taken for charge into crucible made from graphite and Al 2219 is heated above liquids temperature up to 7500 -8000 C for melting. The mixed Al2O3 and MoS2 were added in to molten metal; stirring is carried out at 150- 200 rpm for time duration of 5 min. The particles started distribute around monolithic Al 2119 and then slurry is poured in to cast iron mould.

Niranjan D B et, al, [19] Concludes The reinforcement used is boron carbide and Molybdenum disulphide. The resistance furnace used for prepare hybrid composite by two stage stir casting technique. The Al2219 matrix melted at temperature 750ºC. The preheated reinforcements B4C and MoS2 [at 250ºC] were introduced to molten metal. Stirring action is accomplished by zirconium coated stainless steel at 250 rpm about 5-6 min.

Bharath.et.al (2014) synthesized metal matrix composite using 6061Al as matrix material reinforced with ceramic Al2 O3 particulates using stir casting technique [20].

Ramnath.et.al (2014) fabricated metal matrix composite with aluminium alloy, alumina (Al2O3) and boron carbide by stir casting which involved the mixing of the required quantities of additives into stirred molten aluminium [21].

Hossein.et.al (2014) manufactured Al–nano MgO composites using A356 aluminium alloy and MgO nanoparticles via stir casting. Introduction of MgO nanoparticles to the Al matrix caused increasing of the hardness values. [22].

Padmavati.et.al (2014) investigated the friction behaviour of Al6061 with various percentage volumes of Multiwall carbon nanotube and Silicon Carbide reinforcement through stir casting method. Under mild wear conditions, the composite exhibited lower wear rate and friction coefficient in contrast to Aluminium. [23].

Rajeshkumar.et.al (2014) manufactured composite material by reinforcement of SiC, Al_2O_3, and graphite particles into the matrix of Al alloy. Addition of reinforcement enhanced the mechanical, metallurgical and tribological properties of composite produced as compared to the original alloy of aluminium. [24].

Hariprasad.et.al (2014) explored the wear behaviour of Al 5083 composites manufactured by stirring technique reinforced with Al2 O3 and B4 C. The exploration of wear resistance inferred that with the increase of weight percentage of reinforcements wear resistance increased along with light adhesive wear of the samples. [25].

Shashiprakash.et.al (2014) investigated A356/SiC metal matrix composite made-up by electromagnetic stir casting. It was inferred that type of fabrication process and percentage of reinforcement are the effectual factor influencing the mechanical properties. [26].

Suresh.et.al (2014) reinforced Al6061 with various percentages of TiB2 particles by using high energy stir casting method. The tensile and ultimate strength of the Al6061 increased with increase in the amount of TiB2.Wear resistance and coefficient of friction of Al6061 alloy by the addition of TiB2 decreased with increased TiB2.[27]

Mazahery.et.al (2013) investigated, the effect of the volume fraction of the nano-SiC particles on the mechanical properties of the Al–Si matrix composites fabricated by stir casting technique. The yield strength and tensile strength increased, but the elongation decreased with the increase in the volume fraction of the SiC particles. [28].

Karabaei.et.al (2013) used a novel approach to fabricate Al2 O3 nanoparticles reinforced aluminium composites. To avoid agglomeration of nanoparticles in matrix. Al2 O3 nanoparticles were separately milled and were incorporated into A356 alloy via stir casting method [29].

Tahamtan.et.al (2013) fabricated Al2 06 / Al2 O3 p cast composites by the injection of reinforcing particles into molten Al alloy in two different forms i.e. as Al2 O3 particles and milled particulates of alumina in the process of stir casting [30].

Umanath.et.al (2013) investigated the wear behaviour of Al6061-T6 discontinuously reinforced with silicon carbide (SiC) and aluminium oxide (Al2 O3) composite. The results revealed that the wear resistance of the 15% hybrid composite is superior to that of the 5% composite. [31]

Method	Range of shape and size	Range of volume. fraction	Damage to reinforcement	Cost
Stir casting	wide range of shapes; Larger size; up to 500 kg	Up to 0.3	No damage	Less expansive
Squeeze casting	limited by pre form shape Up to 2cm height	Up to 0.5	severe damage	Moderate expansive
Powder metallurgy	wide range; restricted size		reinforcement fracture	Expansive
Spray casting	Limited shape, large shape	0.3-0.7		Expansive

Table 1 Comparative evaluation for different techniques used in fabrication of AMMNCs

From all the above literature we gone which concludes among the various processes of manufacturing prevalent for discontinuous nano hybrid metal matrix composites, particularly stir casting is accepted as a favourable method, which is also commercially viable. Stir casting is advantageous for mass production of composites for being simple and flexible in nature along with cost effectiveness. As it is low-cost comparably and also offers wide selection of materials. Further, it produces better bonding of reinforcements with the matrix, due to the uniform stirring action.

It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the Available routes for metal matrix composite production and allows very large sized components to be fabricated.

III.TYPES OF REINFORCEMENTS TO ALUMINIUM METAL MATRIX COMPOSITES (AMCs)

1. SILICON CARBIDE REINFORCED AMC

The mechanical properties of siC reinforced AMCs have been studied extensively. The studies found that with the increase in reinforcement ratio, tensile strength, hardness and density of AMC material increased, but impact toughness decreased [32, 33]. A comprehensive study has been carried out to investigate the fatigue and fracture behaviour of AMC reinforced with SiC particles. These studies concluded that the fatigue damage initiates on the particle-matrix interface and it propagates by the particle fracture and interface deboning [34, 35] Srivatsan et al. [36] have investigated the high cycle fatigue and fracture behaviour of 7034/SiC/15p-UA and 7034/SiC/15p-PA MMC. The modulus, strength and the ductility of the two composite microstructures decreased with an increase in temperature. The degradation in cyclic fatigue life was more pronounced for the under-aged microstructure than the peak-aged microstructure. Also, for a given ageing condition, increasing the load ratio resulted in higher fatigue strength. Prabhut et al. analysed the influence of stirring speed and stirring time on distribution of particles in SiC AMC. Uniform hardness values were achieved at 600 rpm with 10min stirring. Chawla et al.[37]. They found that increasing volume fraction (10%, 20% and 30%) and decreasing particle size (down to 5 μm) resulted in an increase in fatigue resistance. Koh et al [38]. They found that the composites and the unreinforced matrix alloy showed cyclic hardening behaviour. The composite containing higher volume fraction of SiC particles exhibited a more pronounced strain-hardening rate leading to shorter fatigue life at a given strain amplitude. The inferior strain-life of the composite can be attributed to the low ductility and the corresponding poor resistance to cyclic plasticity caused by the brittle reinforcement. Razaghian et al. [40] concludes particle fracture was the main damage mechanism prior to final fracture at room temperature, while interface deboning together with inter-particle voids were dominant features in fracture at high temperature. At room temperature, particle fracture was observed at clusters of particles as well as in large particles, whereas at high temperature voids nucleated in the matrix closely adjacent to particles and at particle ends.

2. ALUMINIUM OXIDE REINFORCED AMC

Aluminium oxide (Al2O3), commonly referred to as Alumina, possesses strong ionic inter atomic bonding giving rise to its desirable materials characteristics. Thus, this Al2O3 material attracted significant attention to the researchers while producing AMC and many studies has been carried out to investigate the mechanical and fatigue properties of Al2O3 reinforced metal matrix composites to ensure the effective utilization of the AMC. The characterization of A359/Al2O3 MMC developed by electromagnetic stir casting method was investigated by Kumar et al. [39]. Their study revealed that the electromagnetic stirring action helps to produce smaller grain size MMC and maintains good bonding in Al2O3 particle-matrix interface. Park et al. [41] investigated the effect of Al2O3 in Aluminium for volume fractions varying from 5-30% and found that the increase in volume fraction of Al2O3 decreased the fracture toughness of the MMC. This is due to decrease in inter-particle spacing between nucleated micro voids. Abouelmagd [42] studied the hot deformation and wear resistance of powder metallurgy aluminium metal matrix composites. It was found that the addition ofAl2O3 andAl4C3 increases the hardness and compressive strength. The addition ofAl4C3 improved the wear resistance of the MMC. Jong et al. [44] compared the properties of two aluminium metal matrix composites Al-B_2O_3-TiO_2 system and Al-B-TiO_2 system. Al-B_2O_3-TiO_2 had more fatigue strength then Al-B-TiO_2. Abhishek Kumar et al [43] experimentally investigated the characterization ofA359/Al2O3 MMC using electromagnetic stir casting method. They found that the hardness and tensile strength of MMC increases and electromagnetic stirring action produces MMC with smaller grain size and good particulate matrix interface bonding.

3. BORON CARBIDE AND MOLYBEDNUM DISULFIDE REINFORCED AMC

Boron carbide (B4C) is one of the most promising ceramic materials due to its attractive properties including high strength, low density, extremely high hardness (the third hardest materials after diamond and boron nitride), good chemical stability, High fracture and fatigue. Therefore the manufacturing process of boron carbide and molybdenum disulfide reinforced AMC has widely investigated by many of researcher.

Siddesh et al.[45] Concludes the hybrid composites were successfully fabricated by taking B_4C and MoS_2 reinforced Al 19221 using stir casting technique.$K_2T_iF_6$ halide salt was incorporated in order to improve wettablity between Al and B_4C and also achieve uniform and fairly metal from matrix Al2219 to steel surface.

Siddesh et al. [46] concludes Al 2219 reinforced B4C and MoS_2 were produced effectively by stir casting technique. fairly uniform distribution of B4C and MoS_2 particles were observed with addition of $K_2T_iF_6$ improves wettablity and two stage addition elements clustering of particles XRD analysis shows the phases of Al, B_4C and MoS_2 confirms the incorporation of reinforcements were present in hybrid composites. The mechanical properties like ultimate tensile strength and yield stress of hybrid composites decreases due to crack propagation and particle pull out of MoS2 particle. The fracture surface of Al 2219 shows ductile fracture with dimple and tear ridges pattern.

Haftirman et al. [47] concludes that fatigue crack growth of aluminium alloy decreases significantly with increasing thickness, and the crack initiates very fast on aluminium alloy material. Based on the number of cycles was found similar result that the crack size of 12.7 mm was faster than size of 20 and 15.8 mm. This conclusion should assist the designer in optimizing aluminium alloy selection for fracture resistant aluminium engineering structures.

M. N.Choudhari et al.[48] concludes the homogenous dispersion of B_4C particles exhibits a grater wettablity with aluminium alloy was observed during microstructure evaluation under optical microscope with the increment of B_4C reinforcement in Al 2219 alloy matrix both fatigue and fracture improved as compared to base metal.

Niranjan D B et al. [49] investigates the prepared composite having uniform distribution of B4C and MoS2 this is by examine the composite under FESEM. By adding B4C and MoS2 it makes increase in bearing load to open the crack front. As compared to base alloy and all composites, the composite Al2219-3 wt% B4C-5 wt%MoS2 is higher load withstand but affected to comparatively less fracture toughness to Al2219-3 wt% B4C-4 wt%. But rise in adding Molybdenum disulphide makes increase in extension after crack and increase in load to open the crack front because of its soft nature property.

Niranjan D. B[50] concludes Effect of addition of reinforcement comprise the interparticle arrangement, makes strong obstacle to open the crack front, which results in increase in fracture toughness up to 27% maximum for Al2219-3%B4C-4%MoS2 hybrid composite.

4. FIBER REINFORCED AMC

Ding et al. [32] investigated the low cycle fatigue behaviour of the pure Al reinforced with 20% Al2O3 fiber in total strain controlled mode. They found that the predicted fatigue lives coincide with the observed fatigue lives over a wide range of strain amplitudes for a wide range of test temperatures. However, the predicted fatigue live coincide best with the observed fatigue lives only at the large levels of cyclic plastic strain and total strain. Ding et al. [51] investigated the behaviour of the unreinforced 6061 aluminium alloy and short fibre reinforced 6061Al alloy MMC. They found that the addition of high-strengthAl2O3 fibres in the 6061 aluminium alloy matrix will not only strengthen the microstructure of the 6061 aluminium alloy, but also channel deformation at the tip of a crack into the matrix regions between the fibres and therefore con- strain the plastic deformation in the matrix which leads in reduction of fatigue ductility. Woei-Shyan Lee et al. [54] studied the effects of strain rate on the properties and fracture behaviour of laminated Carbon fiber reinforced 7075-T6Aluminium alloyed found that the flow stress increases with strain rate, but decreases with temperature. Work hardening rate decreases with increase n strain and temperature. Greater density of Al debris and fiber fracture was found at high strain rate for all temperature. Shi et al. [53] studied the morphology and interfacial characteristics of aluminium matrix composites reinforced with the diamond fiber. The composite exhibit high thermal conductivity and low thermal expansion coefficient. Pressure-less metal infiltration process results in good bonding between the diamond fibers and the aluminium-matrix. Sayman et al. [52] studied the elasto plastic stress analysis of aluminium and stainless steel fiber and found that under 30 MPa pressure and at a temperature of 600 C, good bonding between matrix and fiber was observed, moreover increase in the load carrying capacity of the laminated plate was also visualised

5. ZIRCON REINFORCED AMC

Jenix Rina et al. [55] compared the properties of Al6063 MMC reinforced with Zircon Sand and Alumina with four different volume fractions of Zircon sand and Alumina with varying volume fractions of (0+8)%, (2+6)%, (4+4)%, (6+2)% and (8+0)%. The hardness and the tensile strength of the composites are higher for (4+4) %. In this combination, the particle dispersion is uniform and the pores are less where inter-metallic particles are formed. Sanjeev Das et al. [56] comparatively studied the abrasive wear of Al-Cu alloy with alumina and Zircon sand particles and found that wear resistance of the alloy increases significantly after the addition of alumina and zircon particles. However, zircon reinforced composites showed better wear resistance than that of alumina reinforced composite due to its superior particle matrix bonding. Scudino et al. [57] investigated the mechanical properties of Al-based metal matrix composites reinforced with Zircon-based glassy particles produced by powder metallurgy. The test results showed that the compressive strength of pure Al increases by 30% with 40% volume of glass reinforcement. While the volume fraction of the glassy phase increasing to 60%, the compressive strength further increases by about 25%.

6. FLY ASH REINFORCED AMC

Fly ash particles are potential discontinuous dispersions used in metal matrix composites due to their low cost and low density reinforcement which are available in large quantities as a waste by product in thermal power plants. The major constituents of fly ash are SiO_2, $Al2O_3$, Fe_2O3, and CaO. Zuoyong Dou et al. [58] the composite have effective shielding property in the frequency range of 30khz-1.5ghz but the addition of fly ash particulate decreases the tensile strength of the composites Ramachandra and Radhakrishna [59] experimentally found that the wear resistance of Al MMC increases with the in- crease in fly ash content, but decreases with in- crease in normal load and sliding velocity, and also observed that the corrosion resistance decreases with the increase in fly ash content.

IV. CONCLUSION

Several challenges must be addressed in order to strengthen the engineering usage of AMCs such as processing technique, impact of reinforcement and effect of reinforcement on the mechanical properties and its corresponding applications. The major conclusions derived from the prior works carried out can be summarised as below:

- The increase in reinforcement ratio and decrease in reinforcement particle size significantly improves the mechanical and fatigue properties of AMCs

- The increase in volume fraction of Al2O3 decreases the fracture toughness of the AMCs. The addition of fly ash particles as reinforcement is advantages for obtaining high structural homogeneity in AMCs

- The Al2219 reinforced B4C and MoS2 were produced effectively by stir casting technique, fairly uniform distribution of B4C and MoS2 particles were observed. With addition of K2TiF6 improves wettablity and two stage addition eliminate clustering of particles.

- The fracture surface of Al2219 shows ductile fracture and dimple pattern in nature, whereas for hybrid composites both brittle and ductile fracture with dimple and tear ridges pattern. The specific wear rate at low sliding velocity is low and for higher sliding velocity is high and as the sliding velocity increases the specific wear rate increases

- The homogenous dispersion of B4C particles in the metal matrix was exhibit a greater wettablity with aluminium alloy, was observed during microstructure evaluation under optical microscope. With the increment of B4C reinforcement in Al 2219 alloy matrix, both fatigue life and fracture toughness gets improved due to reinforcement type, size and uniform distribution of particles in the matrix. Analysis shows that, 4 wt% of B4C reinforcement in Al 2219 matrix has improved the fatigue life by 63.97% and fracture toughness by 33.34% over Al 2219 alloy.

- Effect of addition of reinforcement comprise the interparticle arrangement, makes strong obstacle to open the crack front, which results in increase in fracture toughness up to 27% maximum for Al2219-3%B4C-4%MoS2 hybrid composite.

REFERENCES

1. Miracle, D. B., ‘‘Metal matrix composites-from science to technological significance’’, Compos. Sci. Technol., 65 (15–16), pp. 2526–2540 (2005).
2. Garcia-Romero A. M., Egizabal P. and Irisarri A. M., ‘‘Fracture and fatigue behaviour of aluminium matrix composite automotive piston’’, Appl.Compos. Mater., 17, pp. 15– 30 (2010)
3. Adiamak M. ‘‘Selected properties of aluminium base composites reinforced with intermetallic particles’’, J. Achiev. Matls Manufac. Tech., 14(1–2), pp. 43–47 (2006)
4. Surappa M. K. ‘‘Aluminium matrix composites: challenges and opportunities’’, Sadhana, 28 (1–2), pp. 319–334 (2003)
5. . Soboyejo W. O., “Mechanical Properties of Engineered Materials”, Marcel Dekker Inc., New York, USA pp. 1–608 (2003)
6. B. D. Dunn, “The corrosion properties of Spacelab structural alloy aluminium 2219 - T851”, Published by: ESA Scientific and Technical Publications Branch, ESTEC, Noordwijk (NL) Printed in The Netherlands ISSN 0379 – 4067
7. D.L. McDanels // Metall. Trans. A 16 (1985) 110
8. M. N. Wahab, A. R. Daud and M. J. Ghazali ” preparation and characterization of stir cast-aluminum nitride reinforced aluminum metal matrix composites” international journal of mechanical and materials engineering (ijmme), vol. 4 (2009), no. 2, 115-117
9. Hossein Abdizadeh, Reza Ebrahimifard, Mohammad Amin Baghchesara, “Investigation of microstructure and mechanical properties of nano MgO reinforced Al composites manufactured by stir casting and powder metallurgy methods: A comparative study”, Composites: Part B 56,PP: 217–221, 201
10. Amal E. Nassar, Eman E. Nassar, “Properties of aluminum matrix Nano composites prepared by powder metallurgy processing”, Journal of King Saud University – Engineering Sciences, 2015
11. M. Ramachandra, A. Abhishek, P. Siddeshwar, V. Bharathi, “Hardness and Wear Resistance of ZrO2 Nano Particle Reinforced Al Nanocomposites Produced by Powder Metallurgy”, Procedia Materials Science 10, PP. 212 – 219, 2015.
12. A.J. Knowles, X. Jiang, M. Galano, F. Audebert, “Microstructure and mechanical properties of 6061 Al alloy based composites with SiC nanoparticles”, Journal of Alloys and Compounds 615,PP. S401– S405, 2014
13. Umma A, Maleque M.A, Iskandar I.Y and Mohammed Y.A, 1R.Raja, 2M.Rajkumar “Carbon Nano tube Reinforced Aluminium Matrix Nano-Composite: a Critical Review”, Australian Journal of Basic and Applied Sciences, 6(12), PP. 69-75, 2012
14. Aakanksha suryawanshi and Shekhar“Analysis of defects in centrifugal casting by hybrid method”,2(4),2014,417-428
15. R.Raja, M.Rajkumar “a short note on manufacturing process of metal powders” ISSN 2320-7345Vol.3 Issue.7, Pg.: 120-128 July 2015
16. Krishna P, Bilkey KT, Pehlke RD (2001) “Estimation of Interfacial Heat Transfer Coefficient in Indirect Squeeze Casting. AFS Transactions 109: 1-9. ”
17. Manjunath Patel GC, Krishna P and Parappagoudar MB “Modelling in Squeeze Casting Process-Present State and Future Perspectives”
18. Siddesh Kumar N G , G S Shiva Shankar, S.Basavarajappa, G.S. Shashi Kumar “Dry Sliding Wear Behaviour of Al 2219/Al2O3-MoS2 Metal Matrix Hybrid Composites Produced by Stir Casting Route”
19. Niranjan D B1, a * ,G S Shiva Shankar1, Experimental Determination of Fracture Toughness for Hybrid MMC Reinforced with B4C and MoS2
20. Bharath V, Nagaral M, Auradi V and Kori S A 2014 Preparation of 6061Al-Al 2 O 3 MMC’ s by Stir Casting and Evaluation of Mechanical and Wear Properties Proc. .Intl. Conf. on Mat.& Characterisation (Hyderabad) vol.6 (India: Hyderabad/Elsevier) p1658
21.] Ramnath B V, Elanchezhian C, Jaivignesh M, Rajesh S, Parswajinan C and Ahmed A S 2014 Evaluation of mechanical properties of aluminium alloy – alumina – boron carbide metal matrix composites Materials & Design 58 332–38.
22. Abdizadeh H, Ebrahimifard R and Amin M 2014 Investigation of microstructure and mechanical properties of nano MgO reinforced Al composites manufactured by stir casting and powder metallurgy methods : A comparative study Compos. Part B.56. 217–21

23. Padmavathi K R and Ramakrishnan R 2014 Tribological behaviour of Aluminium Hybrid Metal Matrix Composite Proc. Global Congress on Manuf. & Mgt.(Chennai) .vol 97(India: Chennai/Elsevier) p 660.
24. Rajeshkumar G B and Parshuram M S 2014 Preparation of Aluminium Matrix Composite by using Stir Casting Method & it ' s Characterization International Journal of current Engg. & Technology.3 148-155
25. Hariprasad T, Varatharajan K and Ravi S 2014 Wear Characteristics of B 4 C and Al2 O3 Reinforced with Al 5083 Metal Matrix based Hybrid Composite Proc. Global Congress on Manuf. & Mgt.(Chennai) .vol 97(India: Chennai/Elsevier) p 925.
26.] Prakash S, Sharma S and Kumar R 2014 Microstructure and Mechanical Properties of A356 / SiC Composites Fabricated by Electromagnetic Stir Casting Proc.Intl. Conf. on Mat.& Characterisation(Hyderabad) vol.6 (India:Hyderabad/Elsevier) p 1524
27. Suresh S, Vinayaga N S, Vettivel S C and Selvakumar N 2014 Mechanical behaviour and wear prediction of stir cast Al – TiB 2 composites using response surface methodology J. Mater,59. 383–96
28. Mazahery A and Shabani M O 2013 Plasticity and microstructure of A356 matrix nano composites J. King Saud Univ. - Eng. Sci 25 41–48.
29. Akbari M K, Baharvandi H R and Mirzaee O 2013 Fabrication of nano-sized Al2 O3 reinforced casting aluminum composite focusing on preparation process of reinforcement powders and evaluation of its properties Compos. Part B 55 426–32.
30. Tahamtan S, Halvaee A, Emamy M and Zabihi M S 2013 Materials and Design Fabrication of Al / A206 – Al2 O3 nano / micro composite by combining ball milling and stir casting technology Mater. Des 49. 347–59.
31. Umanath K, Palanikumar K and Selvamani S T 2013 Analysis of dry sliding wear behaviour of Al6061 / SiC / Al2 O3 hybrid metal matrix composites Compos. Part B 53 159–168.
32. Ozben, T, Kilickap, E., and Cakir, O, 2008, "Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC", J. Mater. Process. Technol., 198: 220-225.
33. Meena, K. L., Manna, A. Banwait, S. S., and Jaswanti, 2013, "An analysis of mechanical properties of the developed Al/SiC-MMC's", American J. of Mech. Eng., 1: 14-19.
34. Iqbal, A. A., Arai, Y., Araki, W., 2013, "Effect of hybrid reinforcement on crack initiation and early propagation mechanisms in cast metal matrix composites during low cycle fatigue", Materials and Design, 45, pp. 241-252
35. Iqbal, A. A., Arai, Y., Araki, W., 2014, "Fatigue crack growth mechanism in cast hybrid metal matrix composite reinforced with SiC particles and Al2O3 whiskers", 24, pp. 1-13.
36. Srivatsan, T. S., and Hajri, M., 2002, "The fatigue and final fracture behaviour of SiC particle reinforced 7034 aluminium matrix composites", compos: Part B, 33, pp. 391-404.
37. Chawla, N., Andres, C., Jones, J. W., and Allison, J. E., 1998, "Effect of SiC volume fraction and particle size on the fatigue resistance of a 2080 Al/SiC composite", Metall. Mater. Trans. A, 29, 2843-2854.
38. Koh, S. K., Oh, S. J., Li, C., and Ellyin, F., 1999, "Low-cycle fatigue life of SiC particulate- reinforced Al–Si cast alloy composites with tensile mean strain effects", Int. J. Fatigue, 21, pp. 1019–1032.
39. Kumar, A., Lal, S., and Kumar, S., 2013, "Fabrication and characterization of A359/Al2O3 metal matrix composite using electromagnetic stir casting method", J. Mater. Res. Technol., 2, pp. 250-254.
40. Razaghian, A., Yu, D., and Chandra, T., 1998, "Fracture behaviour of a SiC particle reinforced aluminum alloy at high temperature", Compos. Sci. Technol., 58, pp. 293–298.
41. B.G. Park, A.G.Crosky and A.K.Hellier // Composites: Part B 39 (2008) 1270
42. R.G. Vogt, Z. Zhang, T.D. Topping, E.J. Lavernia and J.M. Schoenung // Materials Processing Technology 209 (2009) 5046
43. Abhishek Kumar, Shyam Lal, Sudhir Kumar Noida, In: JMRTEC-40.
44. S.C. Tjong, G.S. Wang, L. Geng and Y.W. Mai // Composites Science and Technology 64 (2004) 1971.
45. Siddesh Kumar N G,G S Shiva Shankar ,S.Basavarajappa and G.S. Shashi Kumar" Dry Sliding Wear Behaviour of Al 2219/Al2O3-MoS2 Metal Matrix Hybrid Composites Produced by Stir Casting Route". [Vol.01 Issue.01 June 2015].
46. Siddesh Kumar N G, G S Shiva Shanka, S.Basavarajappa,"Synthesis of Metal Matrix Hybrid Composites and Evaluation of Mechanical and Tribological properties". Applied Mechanics and Materials Vols. 813-814 (2015) pp 121-126
47. Haftirman, Haris Wahyudi1, Julpri Andika, and Noor Afifah Yahadi "Effect of thickness on Fatigue Crack Growth of Aluminium alloys IOP Conf. Series: Materials Science and Engineering". 343 (2018) 012034 doi:10.1088/1757-899X/343/1/012034.
48. M. N.Choudhari, Jayant. K. Kittur "Fatigue and Fracture Toughness Behaviour of Al 2219/B4C Particulate Metal Matrix Composites" Volume VI, Issue I, January 2017 | ISSN 2278-2540
49. Niranjan D B, G S Shiva Shankar, Experimental Determination of Fracture Toughness for Hybrid MMC Reinforced with B4C and MoS2". Vol. 3. Special Issue 8, August-2017 E-ISSN: 2454-8006.
50. Niranjan D.B, G. S. Shiva Shankar and Latha B. Shankar "Study on fracture behaviour of Hybrid Aluminium Composite". MATEC Web of Conferences 144, 02012 (2018) RiMES 2017.
51. H.Z. Ding,H. Biermann and O. Hartmann // Composites Science and Technology 62 (2002) 2189
52. O. Sayman, H. Akbulut and C. Meric // Composites and Structures 75 (2000) 55.
53. J. Shi, R.C. Che, C.Y. Liang, Y. Cui, S.B. Xu and L. Zhang // Composites: Part B 42 (2011) 134.
54. Woei-Shyan Lee, Wu-Chung Sue and Chi-Feng Lin // Composites Science and Technology 60 (2007) 1975.
55. J.Jenix Rino, Dr. D. Sivalingappa, Halesh Koti and V.Daniel Jebin // Journal of Mechanical and Civil Engineering 5 (2013) 72
56. Sanjeev Das, Siddhartha Das and Karabi Das // Composites Science and Technology 67 (2007) 746.
57. S. Scudino, G. Liu, K.G. Prashanth, B. Bartusch, K.B. Surreddi, B.S. Murty and J. Eckert // Acta Materialia 57 (2009) 2029.
58. Zuoyong Dou, Gaohui Wu, Xiaoli Huang, Dongli Sun and Longtao Jiang // Composites: Part A 38 (2007) 186.
59. M. Ramachandra and K. Radhakrishna // Wear 262 (2007) 1450.