A review paper on tribological and mechanical properties of Aluminium metal matrix composites manufactured by different route

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Abstract- Particulate reinforced aluminium matrix composites (AMCs) are attractive metal matrix composite (MMC) materials due to their strength, ductility and toughness as well as their ability to be processed by conventional methods. There are many techniques used to manufacture metal matrix composites, but casting and powder metallurgy are extensively used to manufacture the composites. The powder metallurgy technique is more cost effective than the casting methods, but it cannot be used for the production of complex shapes. Compared with powder metallurgy, casting which involves the stirring of the particles into melt has some advantages: better matrix–particle bonding, easier control of matrix structure, low cost, simplicity, a nearer net shape can be produced and there is a wide selection of materials that can be used in this method. Recently it is shown that aluminium metal matrix composites have superior wear resistance and mechanical properties. This review paper is aimed to summarize tribological and mechanical properties of aluminium alloy matrix composite fabricated by different casting techniques.

Keywords: Aluminium Alloys Matrix, Fabrication techniques, tribological and mechanical properties

I. INTRODUCTION

Aluminum alloys reinforced with particles reiforcement are being extensively used in various field of life, especially in aerospace and automobile industries, because of good thermal stability and excellent specific strength [1,2]. Low weight aluminum alloys lead to reduction of weight resulting in considerable economic advantages [3-6]. Wear behavior of particulate aluminum matrix composites has been extensively studied due to their high secondary workability and superior wear resistance compared to unreinforced metal alloys [7,8]. Aluminium matrix materials can be reinforced with various oxides, carbides, nitrides and borides. SiC and Al_2O_3 are the most common reinforcing material in AMC's limited research has been conducted on B_4C reinforced AMC due to the higher cost of B_4C [11-17]. The ceramic particulate reinforced composites exhibit improved abrasion resistance [18]. They find applications as cylinder blocks, pistons, piston insert rings, brake disks and calipers [19]. The strength of these composites is proportional to the percentage volume and fineness of the reinforced particles [20]. These ceramic particulate reinforced Al-alloy composites led to a new generation tailorable engineering materials with improved specific properties [21]. The structure and the properties of these composites are controlled by the type and size of the reinforcement and also the nature of bonding [22-24].

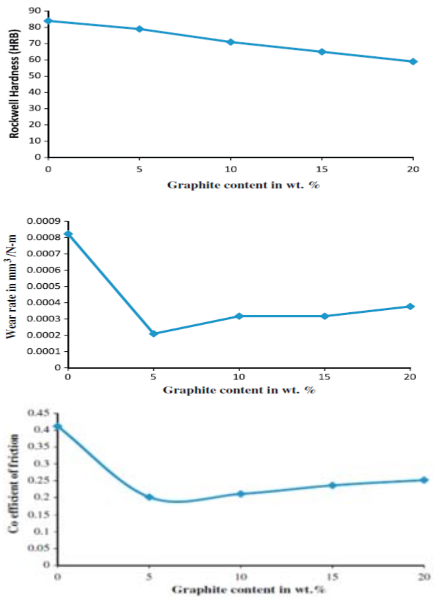
II. Manufacturing Techniques

Metal matrix composites are manufactured using different techniques. These techniques can be classified into liquid phase processes (casting), liquid–solid processes (semi-solid forming) and solid-state processes or powder metallurgy [25, 26]. The powder metallurgy technique is widely used in the manufacture of particle MMCs and it is more cost effective than the casting methods. Compared with powder metallurgy, liquid processing which involves the stirring of the particles into melt has some advantages: better matrix–particle bonding, easier control of matrix structure, low cost, simplicity, a nearer net shape can be produced and there is a wide selection of materials that can be used in this method. However, the casting process has two main problems: first, the reinforcement particles are generally not wetted by the liquid metal matrix, and second, the particles tend to sink or float according to their density relative to the matrix liquid. [27,28].

Semisolid forming has many advantages, such as complex shapes can be formed with some reduction in forming steps and with near net shaping capabilities, less energy consumption, less solidification shrinkage, prolonged die life, good filling of the die and improved mechanical properties [30,31]. The production of raw material for semisolid processing requires specialized techniques such as mechanical stirring, inductive electromagnetic stirring and the cooling slope method. Of all the techniques employed to produce thixotropic microstructure feedstock, the cooling slope casting method is particularly attractive because it is simple, requires a very low amount of equipment and is therefore cost effective [29-31].

Baradeswaran & A. Elaya Peruma [2014] investigated the influence of graphite on the wear behavior of Al 7075/ Al_2O_3/5 wt.% graphite hybrid composite. The composites were fabricated using liquid metallurgy route. Ceramic particles along with solid lubricating materials were incorporated into aluminium alloy matrix to accomplish reduction in both wear resistance and coefficient of friction. The mechanical and tribological properties of the Al 7075–Al_2O_3–graphite hybrid composites were found to be increased by increased weight percentage of ceramic phase as shown in fig(1). The wear properties of the hybrid composites containing graphite exhibited the superior wear-resistance properties [32]. Rao R. N. et al [2013] studied dry sliding wear maps for aluminium matrix composite fabricated by stir casting technique and examined under specific applied load and sliding speed [33]. Taufik R. S. and Sulaiman S. [2013] presented the development of thermal expansion model for casted aluminium silicon carbide [34]. F. Toptan et al. [2013] investigated corrosion behavior of Al-Si-Cu alloy matrix composites reinforced with B4C particulates [35].

M.B. Karamıs et al. [2012] Studied a number of metal matrix composites were manufactured to determine their tribological properties. AA2124 matrix material, reinforced by SiC, B_4C or Al_2O_3 (of different particle sizes), was used for manufacturing by powder metallurgy. The specifics wear rates of the composite reinforced with 10% volume fraction of B_4C or SiC were each lower than that of the GGG40 cam material. While the composites having 30% volume fraction of 20 mm SiC gave the best wear performance, the sample with B_4C showed the best performance at 10% volume fraction as shown in fig. 2, [36]. D. Cree & M.pugh [2011] investigated dry sliding wear and friction behaviors of A356 aluminum alloy and a hybrid composite of A356 aluminum alloy and silicon carbide foam in the form of an interpenetrating phase composite were evaluated using a ball-on-disk apparatus at ambient conditions[37]. Yusuf Shahin [2010] investigated behaviour aluminium alloy matrix reinforced with 15 wt% SiC particles were prepared by powder metallurgy (PM) method. Table 1 summarizes the investigation done by various research groups to study effect of different parameters as per fabrication techniques on tribological and mechanical properties for Aluminium alloys composite [38].



Fig(1): (a). Hardness with varying graphite content (b). Wear rate with varying graphite content(c). coefficient of friction with varying graphite content.

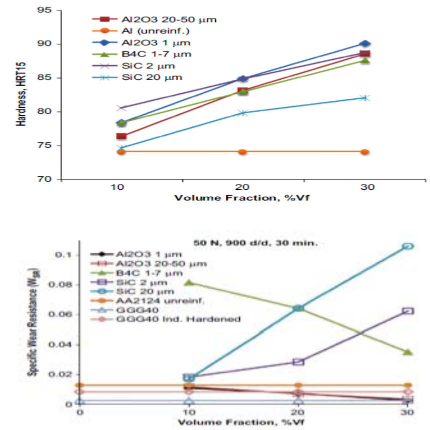


Fig.2: (a). The variation of the composite hardness versus the volume fraction of reinforcement (b). The variation of specific wear with reinforcing particle volume fraction

Table1: Review of Aluminium alloys matrix composites properties.

Author/Group	Fabrication Technique	Parameter	Tribological Properties	Mechanical Properties
A. Baradeswar A. Baradeswaran & A. Elaya Peruma [2014] [39]	Liquid casting	Load: 20-60N Speed: 0.6-1.0 m/s	Wear: .0023-.0034 mm^3/m	Hardness: 115-134 MPa Ultimate Strength: 215-240 MPa Flexural Strength: 330-440 MPa
Yuhai Dou et al. [2014] [40]	Casting	Slidng time:30-120 min Load: 10-40 N Slidng velocity: 60-240m Heat Treatment	Mass loss: 1.6-16.5 mg COF: 0.55-0.59	Hardness: 108-135HB
Gheorghe Iacob et al [2014] [41]	Powder Metallugy		Morphological changes	Hardnrs s: 150-390 HV
M. Lieblich et al.	powder met	load: 42 &140 N	COF: 0.18-0.73	Hardness: 1.08-1.47HV

[2014] [42]	allugy	Varying Mixing method	Volume loss: 11-23mm^3	

Sachin Vijay Muley et al. [2014][43]	Ulionrasonic Vibrations	Load: 500-1500g Sliding Distance:0-3500 Sliding Speed: 1 m/s	Microstructural Analysis Wear: .0026-.014mm^3/m	Compressive Strength: 0-410 MPa Compressive Strain: 0-0.23
Faiz Ahmad et al. [2013] [44]	Casting	Load: 0-100N Sliding Distance:0-1000m	Weight loss: 0.0043-0.103gm COF: 0.16-0.32 Microstructural Analysis	Nil
K.S. Alhawari et al. [2013] [45]	Semisolid processing technique & Stirr Casting	Sliding Distance:0-10Km	Wear: 0.000028-0.00019 mm3/m Microstructural Analysis	Hardness: 62-74BHN
G. Elango &B.K. Raghunath [2013] [46]	Casting	Load: 30-50N Sliding Distance:0-500m	Wear: 0.014-0.04mm 3/m 0.46-0.7 Microstructural Analysis	Nil
J. Gandra et al. [2013] [47]	Friction surfacing	Sliding Distance: 0-300m	Wear: 0.042-0.076mg/m COF: 0.25-0.56 Microstructural Analysis	Hardness: 65-108 HV
Anand Kumar et al [2013] [48]	Casting	Load: 10-30 N Sliding Distance:1000-2000m	COF: 0.41-0.5 Weight loss: 32-69mg Microstructural Analysis	Nil
Ravinder Kumar and Suresh Dhiman [2013] [49]	Stir casting	Speed: 2-6m/s Sliding Distance: 1000-5000m Load: 20-60N	Wear:.000042-.000465 mm^3/Nm Microstructural Analysis	Nil

C.A. Leon-Patino et al [2012] [50]	Directional Infiltration	Speed: 0.3-0.9 m/s Sliding Distance: 0-2000m Load: 103N	Wear: 0.000014-.0076m m^3/m Microstructural Analysis	Hardness: 84-290 HV
P. Ravindran et al. [2013] [51]	Powder metallugy	Speed: 0-3.0 m/s Sliding Distance: 500-3000m Load: 0-30N	Weight loss: 0.0012-0.021 gm COF: 0.02-0.3	Hardness: 52-63 BHN
M. Uthayakumar et al. [2013] [52]	Stir Casting	Speed: 0-6.0 m/s Load: 0-100N Sliding Distance: 0-4000m Temperature: 32-36C	COF: 0.28-0.7 Wear: .000025-0.00027 mm3/m	Nil
F. Toptan et al. [2012] [53]	Squeeze Casting	Speed: 0.02 & 0.03 m/s Load: 20 & 40N Sliding Distance: 200 & 400m	COF: 0.48-0.98 Wear: 0.00650-0.03650 mg/m	Hardness: 119-135HV
Heguo Zhu et al. [2012] [54]	Powder metallugy	Speed: 0.4-0.75 m/s Load: 20-50 N Sliding Distance: 0-200m	Wear: 0.000043-0.000095g/Nm COF: 0.067-0.534	Hardness: 60-77.2HV Ultitimate Strength: 190-215Mpa

III. Conclusion

There are exciting opportunities for producing exceptionally strong, light weight, wear resistant aluminium matrix composites with acceptable ductility by different fabrication route. From the various fabrication process discussed in this paper, mechanical stirring method, it is extremely difficult to distribute and disperse particles uniformly in aluminium metal alloy due to their large surface and volume ratio due to and their low wettability. The hardness and wear resistance of the aluminium allos matrix composite fabricated by cooling slop casting were found to be higher than those of aluminium matrix composite fabricated by using stirring. Powder metallurgy is the branch with a remarkable development for the fabrication of aluminium alloys matrix in recent years due its ability to give more uniform dispersions. Parts produced by this technology require minimal finishing, and have technical/economic advantages which made them very attractive. It is also possible to deposit composite layers by friction surfacing in aluminium based alloys. Multi layering enable to tailoring coating composition in order to achieve pre defined gradient. The multilayer composite coatings present a sound bonding to substrate and between layers with exception of edges.

References

[1].

[2]. S.C.Simon, M.L. McMillan, "Automotive tribology overview of current advances and challenges for the future," Tribol Int, vol. 37, pp.517–36, 2004.
[3]. V.M. Kevorkijan, "Aluminum composites for automotive applications: a global perspective," JOM, vol. 8, pp. 51-54, 1999.
[4]. A. Mazahery, M.O. Shabani, " Nano-sized silicon carbide reinforced commercial casting aluminum alloy matrix: Experimental and novel modeling evaluation," Powder Technology, vol. 217, pp. 558-565, 2012.
[5]. A. Mazahery, M. Shabani, "Characterization of wear mechanisms in sintered Fe-1.5 Wt % Cu alloys," Archives of Metallurgy and Materials, vol. 57(1), pp.93-103, 2012.
[6]. N. Saheb et al., " Influence of Ti addition on wear properties of Al-Si eutectic alloys," Wear, vol. 249(8), pp.656-662, 2001.
[7]. N. Saheb et al., "Microstructure and hardness behaviours of Ti-containing Al-Si alloys. Philosophical Magazine A: Physics of Condensed Matter, Structure, Defects and Mechanical Properties, vol. 82(4), pp. 803-808, 2002.
[8]. N. Chawla, K.K., Chawla, "MetalMatrixComposites," Springer, pp. 67-68, 2006.
[9]. A. P. Sannino, H.J. Rack, "Dry sliding wear of disc continuously reinforced aluminium composite: review and discussion," Wear, vol. 189, pp. 1-19, 1995.
[10]. K. Tokaji, "Fatigue and fracture of engineering materials and structures," vol. 28, pp. 539-545, 2005.
[11]. K.B. Lee et al, "Metallurgical and materials transactions A- Physical metallurgy and materials science," vol. A4-32, pp. 1007-1018, 2001.
[12]. I. Kerti, F. Toptan, " Materials letters," vol. 62, PP. 1215-1218, 2008.
[13]. R. Ipek, "Journal of materials processing technology," vol. 162-163, PP. 71-75, 2005.
[14]. F. Bedir, " Materials and designs," vol.62, pp. 1238-1244, 2008.
[15]. A. Kalkanli, S. Yilmaz, "Materials and design," vol. 29, pp. 775-780, 2009.
[16]. Kerti I., F. Toptan, "Materials letters," vol. 62, pp. 3795-3800, 2008.
[17]. S. Kassim Al-Rubaie, N.Humberto Yoshimura, and Jose Daniel Biasoli de Mello, "Two body abrasive wear of Al–SiC composites," Wear 233–235, pp. 444–454 , 1999.
[18]. L. Ceschini, C. Bosi, A. Casagrande, and G.L. Garagnani, "Effect of thermal treatment and recycling on the tribological behaviour of an AlSiMg–SiCp composite," Wear 251, pp. 1377–1385, 2001.
[19]. Bermudez M.D., Martinez-Nicolas G., Carrion F.J., Martinez-Mateo I., Rodriguez J.A., Herrera E.J., "Dry and lubricated wear resistance of mechanically-alloyed aluminum-base sintered composites," Wear, 248, pp. 178–186, 2001.
[20]. H. Y. Sohn, S. PalDey, "Synthesis of ultrafine particles and thin films of Ni4Mo by the vapor-phase hydrogen coreduction of the constituent metal chlorides," Materials Science and Engineering A, vol. 247,1-2, pp. 165-172, 1998.
[21]. N. Wang, Z. Wang, G.C. Weatherly, "Formation of Magnesium Aluminate (spinel) in Cast SiC Particulate-Reinforced Al(A356) Metal Matrix Composites," Metallurgical and Materials Transactions A, vol. 23, pp. 1423–1430, 1992.
[22]. H. Ribes, M. Suery, G. L. Esperance, J.G. Legoux, "Microscopic examination of the interface region in 6061-Al/SiC composites reinforced with as-received and oxidized SiC particles," Metallurgical and Materials Transactions A, vol. 21, pp. 2489–2496, 1999.
[23]. S.K. Thakur, B.K. Dhindaw, "The influence of interfacial characteristics between SiCp and Mg/Al metal matrix on wear, coefficient of friction and

microhardness," Wear 247, pp. 191–201, 2001.

[24]. S. Amirkhanlou, B. Niroumand, "Development of Al356/SiCp Cast Composites by Injection of SiCp Containing Composite Powders," Journal of Materials & Design, vol. 32, pp. 1895-1902, 2011.

[25]. S.A. Sajjadi. et al., "Fabrication of A356 composite reinforced with micro and nano Al2O3 particles by a developed compocasting method and study of its properties," Journal of Alloys and Compounds, vol. 511, pp. 226– 231, 2012.

[26]. C.G. Kang, S.W. Youn, "Mechanical properties of particulate reinforced metal matrix composites by electromagnetic and mechanical stirring and reheating process for thixoforming," Journal of Materials Processing Technology, vol. 147, pp. 10–22, 2004.

[27]. Lin.et al., "Effects of Mg content on microstructure and mechanical properties of SiCp/Al-Mg composites fabricated by semi-solid stirring technique," Trans. Nonferrous Met. Soc. China, vol. 20, pp. 185-189, 2010.

[28]. M.Z. Omar et al., "Thixoforming of a high performance HP9/4/30 steel," Materials Science and Engineering A, vol. 395, pp. 53-61, 2005.

[29]. M.S. Salleh, M.Z. Omar, J. Syarif, M.N. Mohammed, K.S. Alhawary, "Thermodynamic simulation on thixoformability of aluminium alloys for semisolid metal processing," International Journal of Mathematics and computers in simulation, vol. 7(3), pp. 286-293, 2013.

[30]. M.N. Mohammed, M.Z. Omar, M.S Salleh, M.A. Zailani, K.S. Alhawari, "Joining Two Metals Via partial remelting Method," Journal of Asian Scientific Research, vol. 2(11), pp. 724-730, 2013.

[31]. T. Haga, S. Suzuki, "Casting of Aluminium Alloy Ingots for Thixoforming Using a Cooling Slope," Journal of Materials Processing Technology, vol. 118, pp. 169-172, 2001.

[32]. M.S. Salleh, M.Z. Omar, J. Syarif, , M.N. Mohammed, "An Overview of Semisolid Processing of Aluminium Alloys," ISRN Materials Science pp. 1-9, 2013.

[33]. A. Baradeswaran and A. E. Perumal, "Composites : Part B Study on mechanical and wear properties of Al 7075 / Al 2 O 3 / graphite hybrid composites," *Compos. Part B*, vol. 56, pp. 464–471, 2014.

[34]. R. N. Rao, S. Das, D. P. Mondal, G. Dixit, and S. L. T. Devi, "Tribology International Dry sliding wear maps for AA7010 (Al – Zn – Mg – Cu) aluminium matrix composite," vol. 60, pp. 77–82, 2013.

[35]. R. S. Taufik and S. Sulaiman, "Thermal Expansion Model for Cast Aluminium Silicon Carbide," vol. 68, pp. 392–398, 2013.

[36]. F. Toptan, A. C. Alves, I. Kerti, E. Ariza, and L. A. Rocha, "Corrosion and tribocorrosion behaviour of Al – Si – Cu – Mg alloy and its composites reinforced with B 4 C particles in 0 . 05 M NaCl solution," *Wear*, vol. 306, no. 1–2, pp. 27–35, 2013.

[37]. M. B. Karamıs, "The effects of different ceramics size and volume fraction on wear behavior of Al matrix composites (for automobile cam material)," vol. 289, pp. 73–81, 2012.

[38]. D. Cree and M. Pugh, "Dry wear and friction properties of an A356 / SiC foam interpenetrating phase composite," vol. 272, pp. 88–96, 2011.

[39]. S. Yusuf, "Tribology International Abrasive wear behaviour of SiC / 2014 aluminium composite," vol. 43, pp. 939–943, 2014.

[40]. A. Baradeswaran and A. E. Perumal, "Composites : Part B Wear and mechanical characteristics of Al 7075 / graphite composites," *Compos. Part B*, vol. 56, pp. 472–476, 2014.

[41]. Y. Dou, Y. Liu, Y. Liu, Z. Xiong, and Q. Xia, “Friction and wear behaviors of B 4 C / 6061Al composite,” *Mater. Des.*, vol. 60, pp. 669–677, 2014.

[42]. G. Iacob, V. G. Ghica, M. Buzatu, T. Buzatu, and M. Ionut, “Composites : Part B Studies on wear rate and micro-hardness of the Al / Al 2 O 3 / Gr hybrid composites produced via powder metallurgy,” pp. 2–10, 2014.

[43]. M. Lieblich, J. Corrochano, J. Ibáñez, V. Vadillo, J. C. Walker, and W. M. Rainforth, “Subsurface modi fi cations in powder metallurgy aluminium alloy composites reinforced with intermetallic MoSi 2 particles under dry sliding wear,” *Wear*, vol. 309, no. 1–2, pp. 126–133, 2014.

[44]. S. V. Muley, S. P. Singh, P. Sinha, P. P. Bhingole, and G. P. Chaudhari, “Microstructural evolution in ultrasonically processed in situ AZ91 matrix composites and their mechanical and wear behavior,” *Mater. Des.*, vol. 53, pp. 475–481, 2014.

[45]. F. Ahmad, S. H. J. Lo, M. Aslam, and A. Haziq, “Tribology Behaviour of Alumina Particles Reinforced Aluminium Matrix Composites and Brake Disc Materials,” *Procedia Eng.*, vol. 68, pp. 674–680, 2013.

[46]. K. S. Alhawari, M. Z. Omar, M. J. Ghazali, M. S. Salleh, and M. N. Mohammed, “Wear Properties of A356 / Al 2 O 3 Metal Matrix Composites Produced by Semisolid Processing,” *Procedia Eng.*, vol. 68, pp. 186–192, 2013.

[47]. G. Elango and B. K. Raghunath, “Tribological Behavior of Hybrid (LM25Al + SiC+ TiO2) Metal Matrix Composites,” *Procedia Eng.*, vol. 64, pp. 671–680, 2013.

[48]. J. Gandra, P. Vigarinho, D. Pereira, R. M. Miranda, A. Velhinho, and P. Vilaça, “Wear characterization of functionally graded Al – SiC composite coatings produced by Friction Surfacing,” *Mater. Des.*, vol. 52, pp. 373–383, 2013.

[49]. A. Kumar, M. M. Mahapatra, and P. K. Jha, “Modeling the abrasive wear characteristics of in-situ synthesized Al – 4 . 5 % Cu / TiC composites,” *Wear*, vol. 306, no. 1–2, pp. 170–178, 2013.

[50]. R. Kumar and S. Dhiman, “A study of sliding wear behaviors of Al-7075 alloy and Al-7075 hybrid composite by response surface methodology analysis,” *Mater. Des.*, vol. 50, pp. 351–359, 2013.

[51]. S. Me and C. A. Leo, “Dry sliding wear of gradient Al – Ni / SiC composites,” vol. 301, pp. 688–694, 2013.

[52]. P. Ravindran, K. Manisekar, P. Rathika, and P. Narayanasamy, “Tribological properties of powder metallurgy – Processed aluminium self lubricating hybrid composites with SiC additions,” vol. 45, pp. 561–570, 2013.

[53]. M. Uthayakumar, S. Aravindan, and K. Rajkumar, “Wear performance of Al – SiC – B 4 C hybrid composites under dry sliding conditions,” *Mater. Des.*, vol. 47, pp. 456–464, 2013. [1] F. Toptan, I. Kerti, and L. A. Rocha, “Reciprocal dry sliding wear behaviour of B 4 C p reinforced aluminium alloy matrix composites,” *Wear*, vol. 290–291, pp. 74–85, 2012.

[54]. X. Shi, J. Yao, Z. Xu, W. Zhai, S. Song, M. Wang, and Q. Zhang, “Tribological performance of TiAl matrix self-lubricating composites containing Ag , Ti 3 SiC 2 and BaF 2 / CaF 2 tested from room temperature to 600 ° C,” *Mater. Des.*, vol. 53, pp. 620–633, 2014.

[55]. H. Zhu, C. Jar, J. Song, J. Zhou, J. Li, J. Xie, “ High Temperture Dry Sliding Friction and Wear Behavior of Aluminium Matrix Composites (Al_3Zr+α-Al_2O_3)/Al,” Tribolody International, vol. 48, pp. 78-86, 2012.