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Tribology of aluminium metal matrix composite under lubricated sliding: A Review

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Abstract: -- From the past and till the present scenario, the progress over aluminium metal matrix composites (AMMC) is primarily on the fabrication and mechanical characterization of the composites. The reason for focusing on aluminium composite because of their improved mechanical properties, low density, better corrosion resistance and low production cost are very much suitable for various applications in the field of automotive, aerospace and marine industries. The potential tribological behaviors of these composites are also mainly evaluated through dry sliding friction and wear testing. However, in this paper, in addition to the review of dry sliding applications, an attempt has been made to provide an extensive literature review on the effect of oil and oil additives on the sliding wear and friction behavior of aluminium composite. Due to the ever challenging demand for the minimization of wear and coefficient of friction for the AMMC-steel contact, wet tribology is being used. The authors, along with the sufficient evidences from their own works, show the influence of particle based additives over the conventional wet tribology which implies that the particle additives in oil can significantly enhance the tribological performance if suitably formulated, rather than just going for the base oil and other conventional additives.

Keywords: AMMC, Additives, Lubrication, Wear, Particle.

I. INTRODUCTION

Aluminium metal matrix composites have replaced the conventional metallic alloys in many application such as automobile, aerospace, marines and in various industries due to properties like light weight ,low density, better corrosion resistance, low coefficient thermal expansion, high heat and wear resistant. As these composites are made up of two or more materials; the constituents are matrix and reinforcements which plays a vital role as these reinforcements like silicon carbide, boron carbide, alumina, graphite etc. can be helpful in improving the mechanical as well as the tribological properties as compared to base matrix alloy for the specific applications. The composites can be developed through process like powder metallurgy and liquid metallurgy but our focus is on the liquid metallurgy i.e stir casting. Recently, another approach has been made to produce composites with two or more reinforcements and these composites are called as hybrid composites. Some of the authors have noticed that there is a significant improvement in the hybrid composite as compared to single reinforced even at the reduced processing cost. These hybrid composites produced through liquid metallurgy are considered as high performance and low cost composites [1]. While fabricating through stir casting the various process parameters that should be properly controlled to obtain good metallurgical properties of AMMC are stirrer design, stirrer speed, stirring temperature, stirring time (holding time), preheat temperature of reinforcement, preheated temperature of mould, reinforcement feed rate, wettability-promoting agent, pouring of melt, etc. The fabrication of AMMC by stir casting involves mixing the solid reinforcement followed by continuous agitation in the liquid aluminium and then allowing the mixture of reinforcement and base metal to solidify in a suitable mold. However, problems like increased viscosity, inhomogeneous microstructure and adverse chemical reactions are some of the inherent problems of stir cast fabrication of composites. Due to this, casting of MMCs require critical attentions in some of the process parameters such as viscosity variation due to the addition of reinforcements, minimum reactivity of base metal to the reinforcement, covering the melt with an inert gas atmosphere to reduce the oxidation as well as the stirring of the melt to minimize the settling of particles due to density difference [2]. These AMMC have wide potential tribological applications. Recently, a lots of research is being carried out in the field of dry tribology involving theses AMMCs. However, a very limited literature has been found on the lubricated tribology. Sliding Friction and wear behavior of these composites against steel or other counter surfaces are limited in the literature. There is still a huge gaps exists for the tribological studies of these composites in various sliding conditions and various parameters along with use of types of oil such SN500, PAO4 and PAO6 etc, alongwith the additives used in these oil such as MoS2, boric acid and many more. The objective of this paper is carry out an extensive literature on the use of lubrication as well as the potential additives and particle additives in the wet tribology of AMMC to minimize the friction and wear as compared to the dry sliding conditions.

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II. FABRICATION OF COMPOSITE

Stir casting is a liquid state method which is the simplest and is cost effective to fabricate metal matrix composite. To avoid moisture from the particles, preheating of the reinforced particle should be done; otherwise, there is a chance of agglomeration of particulate which occurs due to moisture and gasses present in the particles. Degassing agents such as hexachloroethane and magnesium are used to reduce the gas porosities. The addition of magnesium helps in reducing solidification shrinkage, hot tearing and reduced agglomeration. The depth of immersion of stirrer should be maintained at about two-thirds of the depth of molten metal. The molten metal is then poured into a permanent mould preheated. Specimen can be left for curing. After the cast is released from die it can be further processed in lathe [3].

Fig 1 stir casting furnace [Courtesy:Thapar University]

III. LUBRICATION

The primary purpose of lubrication is to reduce wear and heat between contacting surfaces in relative motion. Because heat and wear are associated with friction, both effects can be minimized by reducing the coefficient of friction between the contacting surfaces. Stribeck had illustrated the various regimes of lubrication (Fig. 2). Hydrodynamic or full film lubrication is the condition when the load carrying contacting surfaces are separated by a relatively thick film of lubricant. Partial or mixed lubrication regime deals with the state when the velocity is relatively low, the load is high enough or the temperature is sufficiently large to significantly reduce lubricant viscosity.

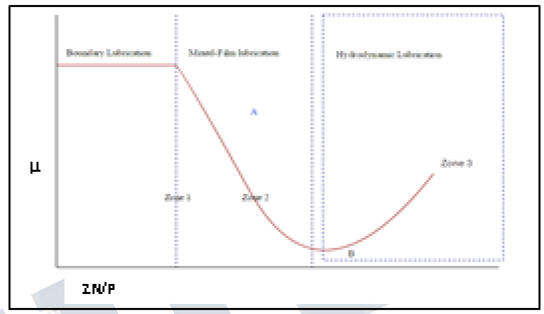

Fig 2 Lubrication regimes[22]

Boundary lubrication regime is the condition when the fluid films are negligible and there are substantial asperity contacts. Base oil is produced by refining crude oil. The types of base oil which can be used are mineral oils such as paraffinic, naphthenic and aromatic oils, synthetic oils and mutli-grade oils such as 10W30, SAE 30, etc. The use of lubricant additives is to counteract high speed , high temperature and high load and plays a vital role to enhance the existing lubricant properties or to impart new properties. Some of the applications like in gears, which are subjected to very high contact pressure, lubricants with extreme pressure additives are required. Some of the particle additives which can be suitable for this purpose are MoS2, boric acid, etc [4].

IV. LITERATURE REVIEW

A.Fabrication and Mechanical characterization of AMMC's

The most conventional method of fabrication of AMMC is carried out using stir casting method in which various processing parameters like temperature, holding time etc. are varied to understand their influence on distribution of particle in matrix and mechanical properties of composites. **Sozhamannan et al**. [5] pointed out that conventional stir casting has some major problems associated with the process. Uneven distribution of particles, inedequate wetting of reinforced particles by metal and heterogeneous dispersion of particles. They examined the cast products by

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microstructure analysis. It was concluded from their microstructure analysis that the uniform distribution of particles occurred in temperature from 7500C and 8000C. Their study also revealed the fact that the holding time influences the tensile and hardness value of the composite[5].

Swamy et al., [6] fabricated Al6061-SiC composites (Fig. 3) using liquid metallurgy route. SiC with varying percentages of SiC (4wt%, 6wt%, 8wt% and 10wt%) was used as reinforcement to improve the hardness, tensile strength and wear resistance of the fabricated composite as compared to the base metals. The cast composites was treated with zing solution followed by quenching in different media such as air, water and ice. The natural and artificial ageing had been done of quenched samples. Mechanical properties such as micro hardness, tensile strength and wear resistance of both matrix Al6061 and Al6061–SiCp composites had been conducted before heat treatment and after heat treatment. Heat treated Al6061–SiCp composites show improved micro hardness, tensile and wear resistance when compared with Al matrix alloy [6].

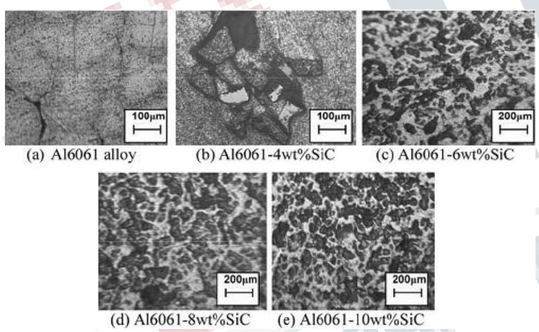

Fig 3 Optical microphotographs of base Al6061 alloy and Al6061–SiCp composites at 4, 6, 8 and 10 wt% SiCp[6]

Kumar et al., [7] studied on Al6061-SiC and Al7075-Al2O3 composites and characterized for tensile strength, As per ASTM standard the sample was prepared from all the composites for hardness, tensile strength, wear and microstructural tests. The increasing percentage of reinforcement content in composites revealed that hardness and density of their composites increases. Optical microscope revealed that uniform distribution of reinforcement into the composites. According to rule of mixture for composites the experimental density value agreed with the theoretical density value of composites. It has been shown that Al6061-SiC reflects superior tensile strength than Al7075-Al2O3 composite. SiC contributed in improving the wear resistance of Al6061-SiC composites which was reflected by the low wear rate of composites [7].

B. Tribo study under dry and lubricated conditions

Singh et. al., [3] have studied the friction and wear behavior AMMC reinforced with SiC and aluminum alloy of 7075 for sliding speeds of 3.14 m/s and 3.77 m/s and load under both dry and lubricated environment. Fabrication of composite took place with the help of stir casting process. MML were found to prevent the plastic flow and wear rate. The experiments were performed on pin on disk tribometer. Composites have showed lower coefficient of friction and wear rates as compared with pure aluminium under dry and lubricated environment. During dry sliding condition coefficient of friction of pure aluminium and the composite decreases with increase in load, whereas it increases with increase in sliding speeds. On the other hand wear rates of both pure aluminium and the composites increase with increase in load as well as with sliding speeds. Wear mechanisms were understood by the FESEM of worn surfaces. The value of COF was found to be minimum in case lubricated condition in composite at sliding speed of 3.14m/s. The values of coefficient of friction and wear rates were minimum in case of both pure aluminum and composite under lubricated condition compared to dry condition. As they increase the normal load and sliding speed, the wear rate increases and it is found to be maximum in dry condition. They also found thin lubricating film formation between sliding surface of specimen and rotating disk surface which decreases the ploughing action and leads to decrease in breakage of small particles from pure aluminium and composite. Which in turn, lowered the wear rates in lubricated condition compared with dry condition, as shown in Fig. 4 [3].

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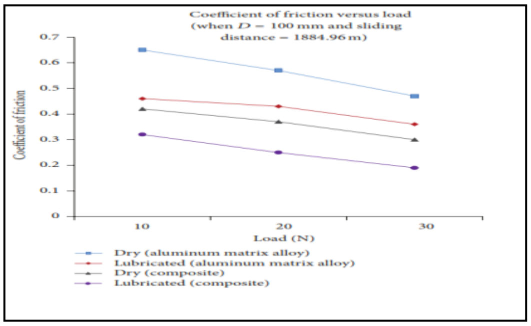

Fig 4 Graph of COF[3]

Martinez et.al [8] have studied the aluminium 6061 and reinforced with inter metallic particles such as Ti3Al, TiB2and TiAl and the comparison had been made between intermetallic particles. The composites were fabricated by P/M route and tribological properties were analyzed in dry sliding and lubrication under SAE 5W40. They explored the evolution of the coefficient of friction with the speed of sliding, applied pressure, regime of lubrication and content of reinforcement in the composites. They highlighted through pin-on-ring experimental results the different mechanisms of sticky and/or abrasive wearing. These mechanisms were analyzed by SEM. Their results show that the reinforcement content affect wear behavior and the wear loss decreases with volume fraction of reinforcement on the composite. Also, the addition of the reinforcement particles improves the wear resistance by improving the hardness of the aluminum matrix. AMMCs reinforced with TiB2 particles show superior wear resistance in dry as much as in lubricated conditions. For the AMMCs reinforced with intermetallic particles, the best wear resistance is given when TiAl used as reinforcement. An important deformation layer was produced on AMCs reinforced with TiAl3 particles, after sliding wear. In AMCs reinforced with TiAl or TiB2 particles some pull-out particles as well as sub superficial cracks are produced after wear tests [8].

Walker et. al. [9] have found out that the beneficial effect of Al-SiC composite can be limited by the abrasive nature of the SiC, leading to increased counter face wear rates. This study reports new Al-alloy composites that offer high wear resistance, reinforced by Cr3Si, MoSi2, NiAl and SiC particles and were prepared by a powder metallurgy route. Lubricated wear studies were carried out using pin-on-ring configuration under commercial synthetic oil Mobil 1 Motorsport. They investigated the lubricated sliding response of two aluminum alloys, 2124 and 5056 and their behavior was compared to similar alloys reinforced with a number of particulate intermetallics, Ni3Al, Cr3Si and MoSi2, as well as with a more conventional SiC ceramic through the same process. NiAl3 had shown superior tribological behaviour as reinforcement under dry sliding conditions. The incorporation of a particulate reinforcement, both ceramic and intermetallic, led to a reduction in the lubricated sliding wear rate of both 2124 and 5056 alloys. However, use of the hard ceramic SiC as reinforcement caused severe abrasion of both contacting surfaces. Wear mechanisms was understand by using SEM[9].

Babic et. al. [10] have used A356 as a base matrix alloy and oil with viscosity grade VG46 (ISO3848) for the the tribological study of A356/10SiC/1Gr hybrid composites. Hybrid composite specimen was obtained by compocasting procedure. Tribological tests were done on an advanced supported tribometer with block-on-disc contact pair under three different values of sliding speed, normal load, different distances and also lubricants. Wear mechanisms were investigated by SEM. It was revealed that with increase of sliding speed, wear rate of the hybrid composite A356/10SiC/1Gr and the base material decreases. Wear test of hybrid composites. Also, A356/10SiC/1Gr show their superior performance in relation to the base material A356.

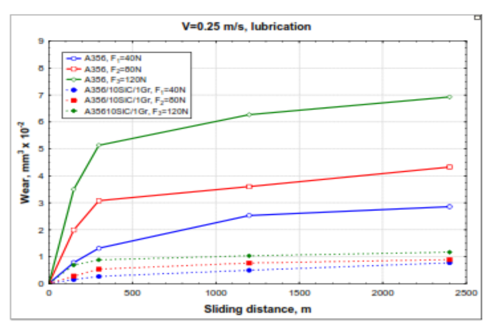

Fig 5 Relationship between sliding distance and wear rate at 0.25m/s sliding speed[15]

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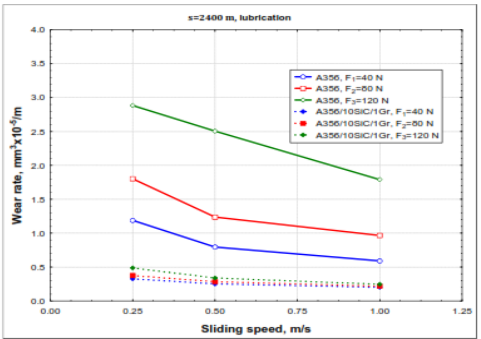

Fig 6 Wear rate dependence on sliding speed[15]

A lots of research also has been carried out on the potential particle additives that can be used for the wet lubrication studies of tribo-pairs. However, they are not yet explored for the tribology of AMMCs. Some of the significant studies in this context are briefly summarized here. Huang et. al. [11] have studied the tribological behaviour of the graphite nano sheets as additive in surfactant span-80 (sorbitol monooleate) laden paraffin oil and investigated with a four-ball and a pin-on-disk friction and wear tester. Ilie &Tita [12] have studied the tribological properties of MoS2 nanoparticles under different friction conditions and these particles mixed in lubricating 15W/40 Super 2 mineral oil using a four-ball tribometer and a block-on-ring tribometer. Rosentsveig et al. [13] have carried out tribological testing using nanoparticles in two synthetic PAO oils and results were compared to bulk (2H platelets) MoS2 and IF-WS2. Tribological performance study had unveiled that the IF nanoparticles strongly depends on their crystalline order and size]. Nunn et al. [14] carried out tribological tests using block-on-ring tester under oil lubrication conditions. Comparison of friction coefficient and wear were performed for PAO oil with nanodiamond particles, single/multiwall carbon nanotubes (SWNT/MWNT) onion-like carbon or nanographene platelets. Hu et al. [15] have studied the tribological properties of liquid paraffin containing MoS2 additives, including nano balls, nano slices, and bulk 2-H MoS2 to imporove these properties of paraffin. The nano balls and slices show better friction reduction as compared to microparticles. The tests were investigated at 50C, rotating speed of 1450 rpm and constant load of 300N and steel with hardness of 61-63 HRC. DÜZCÜKO˘GLU and ACARO˘GLU [16] have studied the wear performances of commercial mineral oil, pure canola oil, and a combination of canola oil and boric acid on a pin-on-disc test apparatus Greenberg et al. [17] studied the tribological properties of IF-WS2 nanoparticles dispersed in API grade I base oils of three different viscosities under different regimes of lubrication and proposed transfer film formation mechanism decreased friction to almost half of its original value in case of mixed lubrication regime. Kalin and Kogovˇsek [18] have tried to compare tribological behavior of MoS2 and WS2 as fullerene-like particles, platelets and nanotubes .The authors come with the fact as described that particle morphology did not significantly affect the coefficient of friction. Singh and Suresh [19] evaluated the tribological properties of nanofluid which is made of base oil and MWCNTs (0.5 wt. %). The extreme pressure and anti-wear properties were studied using Four Ball Tester. The authors concluded with the remark that the nanofluids of such composition are not suitable for low load applications. Bhaumik et al. [20] had investigated the exceptional antiwear (AW) and extreme pressure (EP) properties of multiwalled carbon nanotube (MWCNT) / Grpahite based mineral oil. The wear test results had showed MWCNT as additive in oil decreases the wear upto 75 percent as compared with fresh mineral oil results. There was significant increase in load bearing capacity of contacts using MWCNT based oil in comparison to pure mineral oil. The authors also exposed that MWCNT based oil proved well in terms of AW and EP properties in comparison to graphite based oil. Srinivas et al. [21] studied the extreme-pressure property of 600 N base oil dispersed with nanosized MoS2 particles and polyisobutylenesuccinamide (PIBS) as dispersant. Their results show that the seizure load, weld load and load wear index of nano particles dispersed oils have improved extraordinarily compared to Base oil [23].

V. CONCLUSION

In this paper an attempt is made to present a comprehensive literature review on tribology study of aluminium metal matrix composite under lubricated sliding condition. Most of the works associated so far includes the mechanical characterization and dry sliding wear behaviour of AMMC. Most of the attempts has been made on the fabrication and mechanical testing of the composites. The wet tribological behaviour of AMMC is still in the infancy stage, which has huge potential applications. There are limited literature available on the wet tribology and the influence of additives dispersed in oil to enhance the tribological performance as compared to the simple base oil lubrication. Lastly, there is the requirement for extensive research to harness the benefits of wet tribology of AMMC for the minimizing the friction and wear in the potential applications such as in automotive sectors.

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