A REVIEW ON MECHANICAL AND WEAR BEHAVIOUR OF ALUMINIUM METAL MATRIX COMPOSITES

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ABSTRACT: *The applications of aluminium and its alloys can be found in almost every engineering field such as aerospace, marine, automotive, structural and various other fields. Due to its versatile properties it is preferred for fabricating different types of metal matrix composites. Metal matrix composites exhibit better and improved strength, toughness, formability, corrosion resistance, machinability, stiffness, wear, creep, fatigue and numerous other mechanical properties as compared to metals. With the invention and development of these aluminium metal matrix composites various drawbacks faced by the engineering society have been overcome and best possible solutions are provided. This review paper mainly focuses on the mechanical behavior of various types of aluminium metal matrix composite developed using different fabrication techniques. Main emphasis is on the study of wear behavior of AMMCs with various input conditions, prepared using stir casting process as it is one of the predominantly used fabrication technique.*

1. INTRODUCTION:

Composite material is made of two or more constituent materials with relatively different physical and chemical properties. These when combined produces a material with unique properties whose characteristics differ from that of the original individual components. The constituents are combined at a microscopic level and are not soluble in each other.Composites are classified based on reinforcing material structures and matrix material. Under the sub-classification of matrix material there is metal matrix composites.

1.1 Metal matrix composites (MMCs):

It is a composite material having a minimum of two constituent parts, out of which one is necessarily a metal and the other material may be a different metal or another material, such as a ceramic or organic compound. When the composites consist of more than two different materials then it is said to be a hybrid composites.

MMCs are prepared by dispersing a reinforcing material into a metal matrix. Amatrix is a monolithic material into which the reinforcement is embedded, and is fully continuous. The reinforcement material is embedded into a matrix and is also used to change physical properties such as wear resistance strength, stiffness, friction coefficient, thermal conductivity etc. The matrix phase may consist of metal or metal alloys. The dispersed phase is usually in the form of flakes, fillers, fibres, whiskers, particles, plates, rods, etc. The matrix plays the role of holding the reinforcement to form the desired shape whereas the reinforcement improves the overall mechanical properties of the matrix.

1.2 Aluminium Metal Matrix Composites (AMC):

The abundance of aluminium by mass is about 8% of our earth's crust, making it the most abundant metal and third most abundant element behind oxygen and silicon. The versatile physical and mechanical properties of aluminium such as high stiffness, hardness, specific strength, high temperature resistance, high wear resistance, good abrasion resistance, low density, corrosion resistant etc. contribute towards its wide usage in almost every field such as automobile, aviation industries, structural applications, marine etc. However, the problem of low melting point and low strength of aluminium was one major issue along with the need for creating lighter and stronger materials were prevailing among the engineering community. So the usage of reinforced materials became the best possible solution for this problem and later on the metal matrix composites developed.

1.3 Reinforcement materials:

While selecting reinforcement, certain aspects need to be considered such as type of reinforcement, geometric nature, interfacial characteristics,chemical characteristics, porosity, inclusions etc. Commonly used reinforcement materials are Silicon Carbide (SiC), Aluminium Oxide (Al_2O_3), Boron carbide (B_4C), Tungsten Carbide (WC), Graphite, Carbon nanotubes etc.

Certain industrial and agro wastes like Rice Husk Ash, Fly ash, Red Mud, Bagasse ash, Corn cob ash, Palm Kernel Shell Ash, Maize Stalk Ash etc. are gaining importance these days. Instead of disposing them, they canbe used as a reinforcement material.

1.4 Fabrication Methods:

There are two types of fabrication methods name liquid state fabrications and solid state fabrication of metal matrix composites. Liquid state fabrication involves the incorporation of dispersed phase into molten matrix metal and further it is made to solidify, for example stir casting, squeeze casting liquid metal infiltration, in-situ processing, spray casting etc. In solid state fabrication the metal matrix composites are formed as a result of bonding a matrix metal and a dispersed phase by mutual diffusion occurring between them in solid states at an elevated temperature and pressure, for example powder metallurgy, diffusion bonding, vapour deposition techniques, friction process etc.

1.5 Stir Casting:

Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibres) is mixed with a molten matrix metal by means of mechanical stirring.This is the most prominently used technique (it is also referred to as the vortex technique) is attractive because of simplicity, low cost, flexibility, most economical for large sized components to be prepared as well as production of near net shaped components. This process involves the introduction of pre-treated ceramic particles into the vertex of molten alloy created by the rotating impeller.

Stir Casting is characterized by thecontent of dispersed phase is limited (usually not more than 30 vol %) and distribution of dispersed phase throughout the matrix which is not perfectly homogeneous. There are local clouds (clusters) of the dispersed particles (fibres) and there may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrixphase. The technology is relatively simple and low cost.

Distribution of dispersed phase may be improved if the matrix is in semi-solid condition.The method using stirring metal composite materials in semi-solid state are called as rheocasting. High viscosity of the semi-solid matrix material enables better mixing of the dispersed phase. The figure given below shows the stir casting setup.

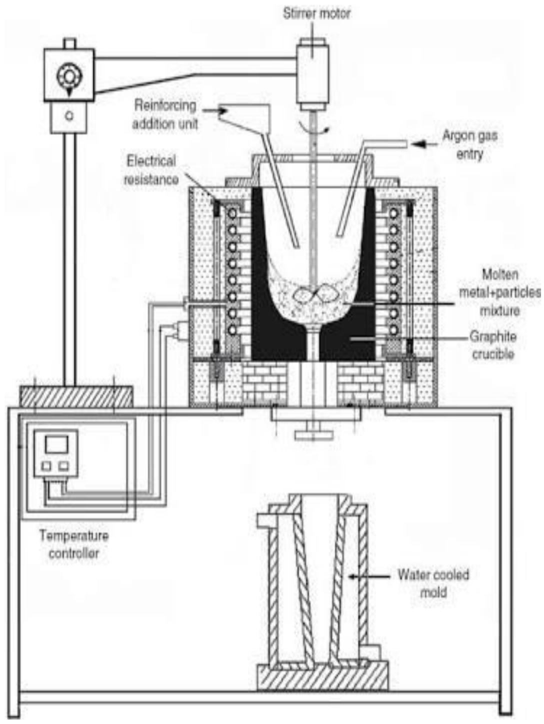

Figure 1 Stir Casting Setup

2. Literature Review

Mondal et al. [1] studied the wear behaviour and analysed the microstructure of Al–Si alloy (ADC- 12) with SiC developed by stir casting process. Addition of ceramic reinforcement such as SiC particles improved the wear resistance of the alloy. Transition in wear mechanism from micro-cutting/ploughing dominated to micro-cracking and fracturing dominated wear took place when abrasive size increased from 100 to 120 mm. The wear resistance increased linearly with increase in SiC content and decreased with increase in reinforcement size.

Uyyurua et al. [3] attempted to study the wear rate, friction coefficient with the variation of applied load and sliding speed. With the help of stir casting technique the Al–Si/15 and 20% SiCp composite was developed. With increase in the applied normal load, the wear rate is observed to increase whereas the friction coefficient decreases. The wear rate and friction coefficients are observed to vary proportionally with the sliding speed. During the wear tests, formation of a protective tribo-layer is observed, which plays a significant role in determining the wear.

Rodriguez et al.[4] fabricated the Al-8090 with 15 vol. % SiCp using Spray co- deposition to study the wear behaviour at different pressures and temperatures. At a transition temperature, the wear rate changed from mild to severe wear for both the composites. The SiC reinforcement addition successfully shifted the transition temperature to higher values which were also dependant on pressure. It has been also observed that the presence of mechanically mixed layers on the wear surface with varying morphology and thickness seemed to be a key factor controlling the mild wear of these materials.

Natarajan et al.[7] investigated the wear behaviour of Aluminium reinforced 5 and 10% TiB2 at elevated temperatures. The metal matrix composite is prepared by In-situ fabrication method.The hardness and wear resistance of TiB2 reinforced composite was higher than the unreinforced matrix alloy at all test temperature and also increased with the increase in amount of TiB2 which enhanced the load carrying capacity of the composite. The wear mechanism of the composites changed from abrasive wear to oxidative wear with the rise of temperature. At high temperature above 2000 C, severe adhesive wear occurs when crack propagation was predominant factor.

Rao and Das [8] reported the effect of heat treatment on sliding wear with applied load and sliding speed of Al-Zn Mg (7009) alloy10, 15 and 25wt.%SiC particle produced by stir casting process. The uniform distribution of SiC particles in aluminium alloy matrix was observed and the dendrites of Al and precipitates along the inter-dendritic regions were present. The maximum hardness was obtained at the peak aging 6h of heat treatment and wear rate increased with increasing sliding speed and load. Addition of SiC particle increased the seizure pressure and temperature.

Kaur et al.[9] analysed the wear rate under different loading conditions and at various temperatures of SiC reinforced Al-Si (along with the SiC 5% and 10% addition) prepared by spray forming fabrication technique. The change in wear mechanism was observed with the increase in applied load. The SiC reinforced composites exhibited better wear resistant than unreinforced alloy even at higher loads due to the oxidative-cum-adhesive wear mechanism.

Kumar et al. [10] attempted to study the hardness and abrasive wear behaviour with different particle sizes using mathematical model the analysis of variance (ANOVA) of AA7075Al reinforced with l5- 25% SiC developed using powder metallurgy process. Hardness of the composite increased with the SiC addition and micrographs showed uniform distribution of the SiC particles. The abrasive wear behaviour clearly indicated the increase in wear resistance as SiC acted as a load-supporting element. Composites with larger reinforcement size and high volume fraction displayed improved abrasive wear resistance as compared to other combinations. At high load, particle pull out was the dominant wear mechanism in composites with finer Silicon Carbide particulate (SiCp), whereas particle fracture and wearing of SiCp was the predominant in composites with coarser SiCp.

Reddappa et al.[12] observed the changes in friction coefficient with variation of applied load and also analysed the wear rates along with hardness values of Al-6061 reinforced with 2, 6, 10 and 15% beryl composites prepared by stir casting method. High friction coefficient was observed due to the strong interlocking of the rough surfaces in contact during the initial stages of sliding. Abrasive wear was dominant in the steady state and a transfer film formed on the surface reduced the wear rate. The increase of load led to a significant increase of the wear rate. As the load increased from lower to higher values, the morphology of the worn surface gradually changed from the scratches to distinct grooves and flake craters.

Toptan et al.[13] experimented on Al alloy reinforced with 15 and 19% B_4C fabricated using squeeze casting route at low vacuum. The studies emphasized the micro-structural features and the reciprocal dry sliding wear behaviour of the prepared composites. The homogeneous distribution of the B_4C particle with decreased porosity was attributed to the addition of Titanium containing flux which promoted the wetting between B_4C and liquid aluminium metal. ANOVA analysis showed strongest statistical and physical significance on the wear rate which was found to increase with volume fraction, load and sliding distance and decreased with sliding velocity. The examinations of the worn surfaces confirmed that wear mechanism was a combination of adhesive, abrasive and delamination wear.

Kumar et al.[14] studied the mechanical and wear properties of Al6061 reinforced with 2- 6 wt.%SiC by stir casting process. Hardness, density, tensile strength increased with the filler content. The wear resistance of the composite was higher than that of the base alloy. The composite with 6 wt% reinforcement exhibited superior mechanical and tribological properties

Zhu et al. [16] investigated the wear behaviour of Al alloy reinforced 20-30% alpha Al_2O_3 and Al_3Zr particles at elevated temperatures using the in situ fabrication technique. With the rise in temperature due to sliding, the work hardening occurred on the wear surface which enhanced the wear resistance of the composite. Recrystallization taking place at the wear surface during the dry sliding have resulted in the decrease in the hardness of the wear surface thus increased the wear loss.

Uthayakumar et al. [17] analysed the coefficient of friction and wear resistance of Al alloy with different particle weight proportions (5,10 and 15%) SiC and B_4C prepared using stir casting method. The B_4C particles enhanced the production of rich tribo-oxide layer by forming boron oxide which has reduced the progress of wear and coefficient of friction. At high loads and sliding velocities plastic deformation was the operating wear mechanism accompanied by the melt wear due to high order of local stress prevailing at the condition.

3. CONCLUSION:

- Among several methods of fabrication, stir casting is mostly preferred due to its convenience and cost effective process.
- Fine Al_2O_3 particles were well distributed in the inter-particles spacing of coarse SiC particles within the matrix which hardened the matrix and decreased the wear rate.
- At lower load, the dominant wear mechanism involves adhesion and micro cutting abrasion. At higher loads abrasive wear involving micro cutting and micro-ploughing with the oxide formation which was the main cause of wear damage.
- Adhesive wear was a predominant mechanism of wear followed by plastic deformation with increase of specific load.
- The dominant wear mechanisms shifted to severe wear when the applied load exceeds the critical load.
- The wear mechanism was abrasive and oxidative at the low loads. All materials have shown a transition to a severe form of wear with a massive removal of wear debris for very high applied loads of 200 N accompanied by the plastic deformation of the surface material
- The addition of the SiC particulates improved the wear resistance by a factor of two in the mild wear region
- Mild to severe wear delay was observed in the composites with the addition of Al_2O_3 and SiC but a hybrid A356 Al composite containing SiC and graphite remained in a mild wear regime even at the highest test temperature of 460°C.
- Particle additions have reduced the wear rate of the composites and hence delayed the transition with load from low wear coefficients to high wear coefficients.
- The addition of higher amount of reinforcement resulted in a reduction in wear rate and further led to the retardation of the load at which wear coefficient increases
- Carbon fibre was more efficient in improving wear resistance of the hybrid composites at high applied load.
- The composite prepared with 10 wt.% B_4C yielded 40% lower wear rate than that of the composite with 5 wt.% B_4C under the same test conditions.
- This experimental result indicated a significant effect of the B_4C particles on enhancing the wear resistance of these composites.

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