Fabrication of Aluminium Based Metal Matrix Composite using Silicon Carbide Reinforcement and Evaluation of Mechanical Properties: a Review

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Abstract— *In Recent years, a great research is carried out on the aluminium metal matrix composites, but since these materials have vast scope in different applications because of lightweight, good mechanical and wear properties. In this paper, a review of aluminium metal matrix composite is carried out, mainly focused on the aluminium alloy Al6061. The fabrication of aluminium metal matrix composite is done by various methods like stir casting, powder metallurgy etc. and stir casting is observed as low cost and it provides a homogeneous mixture of constituents of the composite. The reinforcement particles like aluminium oxide, silicon carbide, titanium diboride, boron carbide, graphite etc. provide different properties like lubrication, wear resistance, tensile strength, low density etc., but it depends on the particles size as well as wt % of the reinforcements. Process parameters like temperature, holding time etc. also have an effect on the composite materials. Aluminium MMC extensively used in the automotive engine components, body parts, brake pads etc.*

Keywords— *Aluminium metal matrix composite, reinforcement; stir casting; alumina; silicon carbide*

I. INTRODUCTION

A composite material is prepared by combining two or more materials – often ones that have very different but possess higher properties. The two materials work together to give the composite unique properties. However, within the composite, it can be easy to tell the different materials apart as they do not dissolve or blend into each other. In composites, one of the materials, called reinforcing phase, is in the form of fibres, sheets or particles and are embedded in the other material called the matrix phase. when combined, the reinforcing material and matrix material can be metal, ceramic or polymer. Typically, reinforcing materials are strong with low densities while the matrix usually a ductile or a tough material.

Composite materials have been one of the major areas of scientific and applied research for many decades; however, only in the past decade they have been viewed and applied as engineering materials. Today we have significant progress and advances in our understanding of these materials and their metallurgical behaviour. The greatest advantage is in the fact that we can inherit properties of both, the metal matrix and the reinforcements, providing a material with properties which can meet specific and challenging requirements in many applications. There is a wide spectrum of the types of metal matrix composite (MMC), each with a specific property profile. Metal matrix composites have been one of the key research subjects in materials science during the past two decades. Most of the work has been dealing with aluminium and other light metal matrices for applications requiring lightweight in combination with a high strength and/or stiffness. Although manufacturing of continuous fibre reinforced Al matrix composites is rather complicated and expensive they are utilized in a few applications, especially in the aerospace industry. However, today most of the emphasis is put on improving the cost efficiency of mass production techniques for particulate reinforced Al matrix composites which have moderate properties but they are much more inexpensive than continuous fibre reinforced materials. A metal matrix composite (MMC) is a composite material consists of two or more constituent parts, one being metal. The other material is ceramic or organic compound, when at least three materials are present it is called hybrid composite.

Metal matrix composites have many advantages over monolithic metals including a higher specific modulus, higher specific strength, better

properties at elevated temperatures, lower coefficients of thermal expansion and better wear resistance. Because of these attributes, metal matrix composites (MMCs) are under consideration for a wide range of applications. Metal matrix composites have many advantages over monolithic metals including a higher However, on the debit side, their toughness is inferior to monolithic metals and they are more expensive at present. In comparison with most polymer matrix composites, MMCs have certain superior mechanical properties, namely higher transverse strength and stiffness, greater shear and compressive strengths and better high-temperature capabilities. There are also advantages in some of the physical attributes of MMCs such as no significant moisture absorption properties, flammability, high electrical and thermal conductivities, and resistance to most radiations. Metal matrix composites have been extensively studied for many years, the primary support has come from the aerospace industry for airframe and spacecraft components. More recently, automotive, electronics and recreation industries have been working diffusively with composites. MMC reinforcements can be generally divided into five major categories: continuous fibres, discontinuous fibres, whiskers, wires and particulate (including platelets). With exception of wires, which are metals, reinforcements are generally ceramics. Typically these ceramics are oxides, carbides, and nitrides which are used because of their excellent combinations of specific strength and stiffness at both ambient temperature and elevated the temperature.

The two most commonly used metal matrices are based on aluminium and titanium. Both of these metals have comparatively low specific gravities and are available in a variety of alloy forms. Although magnesium is even lighter, its great affinity for oxygen promotes atmospheric corrosion and makes it less suitable for many applications. Beryllium is the lightest of all structural metals and has a tensile modulus higher than that of steel. However, it suffers from extreme brittleness, which is the reason for its exclusion as a potential matrix material. Nickel and cobalt-based superalloys have also been used as matrices, but the allo]ying elements in these materials tend to accentuate the oxidation of fibres at elevated temperatures.

The methods of producing Metal Matrix Composites are Solid state methods, Liquid state methods. Solid state method includes powder metallurgy, foil diffusion bonding etc. while liquid state methods include stir casting, squeeze casting, spray deposition etc.. The work is mainly focused on stir casting process to understand the way to get a homogeneous mixture of particulates, reinforcements in the matrix material.

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II. Review of Literature

There has been a wide research is in this field and still, there are many researchers still working in this field to improvise the properties of composites materials because of its wide range of application in different field, so there are many kinds of literature available for aluminium metal matrix composite and some of the relevant are as follows:

Z.Z. Chen et al.[1] studied the effect of particle size on fatigue crack initiation and crack growth in aluminium matrix composites. Aluminium alloy 2024 was taken into consideration for study. Silicon carbide (SiC) was taken in different sizes (5 µm, 10 µm, 60µm) for reinforcement. The material was prepared by using powder metallurgy process. Fully reversed axial fatigue tests were performed using electro servohydraulic fatigue testing machine. Scanning electron microscope and optical microscope were used to study the crack growth path and fracture surface of the specimen.the good fracture resistance and resistance to crack growth was found in silicon carbide particles of size 5µm and 20µm. G. B. Veeresh Kumar et al. [2] carried out the study on Aluminium alloy (AL6061) - Silicon Carbide (SiC) and Aluminium alloy (Al7075)- Alumina (Al_2O_3) metal matrix composite for analyzing the mechanical and tribological properties and compared them. The liquid metallurgy technique (stir casting) was used to fabricate the metal matrix composite. The different weight percentage of reinforced material were used while fabricating the specimens for testing. The microstructure study showed the uniform distribution of the reinforced particles in the matrix. The tensile strength of the composites was found to be higher than base material and also Al6061-SiC showed higher tensile strength properties than that of Al7075-Al_2O_3. Hardness was found to be increasing with the increase in weight percentage of the reinforced particles. The wear resistance properties of composites were improved and also wear resistance of Al6061-SiC was better than the alloy. N. Radhika et al. [3] studied the tribological properties of metal matrix composite of aluminium alloy (Al-Si10Mg) reinforced with alumina and graphite and also the effect of wear parameters like sliding distance, sliding speed and applied on the dry sliding behaviour of Al/Al_2O_3/Gr observed. Taguchi method was used for generating the design of experiments and for analysis of parameters ANOVA technique was used. The liquid metallurgy route was used for fabrication of metal matrix composite. The material and reinforcement were taken in different weight

percentage. For testing the wear behaviour pin on disc test apparatus was used. The test result showed that the sliding distance has the greater effect on wear rate and applied load has also a very significant influence on wear rate and sliding speed has a lesser effect on wear rate. A.R.I. Khedar et al. [4] fabricated aluminium metal matrix composite by taking pure aluminium as a base material and, alumina (Al_2O_3), silicon carbide (SiC) and magnesium oxide (MgO) as reinforcements. The reinforced elements were added individually one at a time in different volume fractions. The stir casting method was used to prepare the composites. During melting and mixing silicon particles were added before reinforcement in order to improve wettability and achieve homogeneous distribution. After testing it was found that improvement in mechanical properties depends upon the addition of particulates and homogeneous distribution depends on the wettability of the material. The addition of reinforcements led to increased mechanical properties such as hardness, tensile strength and yield strength but ductility decreased slightly and the reason was the addition of SiC. The application of these composites in the automotive engine parts. Chang-Yeol Jeong [5] observed the effect of alloying elements on the mechanical properties of Aluminium – Silicon alloys used for the piston. Casting alloys were fabricated by permanent mould casting. Alloying elements such as Fe, Cu, Ni and mg were studied on fatigue and creep behaviour. Chemical compositions of these elements were varied. The results concluded from this paper showed finer microstructure and uniform precipitation with an increase in the content of Ni and Cu. The mechanical properties were improved with an increase in Cu and Ni content and Also creep properties were increased significantly with increasing of Ni and Cu content. G. G. Sozhamannan et al. [6] studied the influence of process parameters of stir casting process on aluminium metal matrix composites. They observed the effect of process parameters such as holding time and processing temperature on uniform distribution of reinforced particles and also on mechanical properties such as ductility, hardness, tensile and impact behaviour. Al-11Si-Mg alloy used as the matrix material. Silicon carbide (SiC) was used as reinforcement. While experimentation and fabrication process the applied different temperatures, different holding time and stirring speed was kept constant. The optimum temperature for uniform distribution was found 750 ^{0}C and 800 ^{0}C. Tensile strength and hardness were found to be increasing with the processing temperature up to 800℃ and with the increase in holding time ultimate tensile strength was found to be decreasing. S. Rama Rao and G. Padmanabhan [7] fabricated aluminium- boron carbide composite and analyzed the mechanical properties of the same. The liquid metallurgy technique was used for fabrication purpose. The reinforce material boron carbide was added in different weight percentage. The microstructure of the composite was studied by scanning electron microscopy and distribution observed was uniform. Hardness and ultimate compression strength were found to be increasing with the increase in the amount of boron carbide particles. Density was decreased with increase in the amount of reinforcement particles. T. Rajmohan et al. [8] evaluated the wear and mechanical properties of hybrid metal matrix composites. As a matrix material, Al356 alloy was used. Silicon carbide and mica were used as reinforcement materials. The stir casting method was used to fabricate the composites. The particulates were preheated before introducing to molten metal in the crucible. The microstructure studied by SEM micrograph was noticeably uniform. The chemical composition was investigated by energy dispersive X-ray (EDX). The optimum result was found at 10% silicon carbide and 3% mica. With increased reinforcement wear characteristics were improved. Dinesh M. Pargunde et al.[9] experimentally observed the properties of aluminium – silicon carbide metal matrix composites. The stir casting method was used for fabrication of composites. Silicon carbide was used in different weight percentage with aluminium alloy. Tests for Hardness, impact strength, microstructure, and corrosion were carried out and it was observed that hardness, density, and impact strength was increased with the increase in weight percentage of silicon carbide, and corrosion rate was found to be satisfactory. Faiz Ahmad et al. [10] attempted to study the wear characteristics of the aluminium metal matrix composite and also investigated about brake disc material. Aluminium alloy 242 was taken as the matrix material and reinforced with alumina particles. Composite was prepared by the squeeze casting process. SEM analysis was carried out to study the surface of test samples. Wear testing of composites and brake disc was done and the results were compared. The test results showed a different type of wear such as adhesive, fatigue and abrasive type were experienced by test samples. With the increased sliding speed, the coefficient of friction decreased and wear resistance increased and for composites, the results were better than brake disc material. Sudindra S et al. [11] experimentally carried out the study on aluminium metal matrix composites. Aluminium alloy 6061 was used as base material and Al_2O_3 and graphite particulates were used as reinforcement materials. Stir casting was used for the preparation of the composites. A different weight percentage of reinforcement materials were used. It was observed that with the addition of Al_2O_3 alone results in increased hardness and tensile strength and decreased wear rate, while the addition of graphite particulates alone results in decreased hardness and increased ductility but the cumulative effect resulted in decreased wear rate and increased tensile strength. Mahendra Boopathi M et al. [12] evaluated the

mechanical properties of the hybrid metal matrix composites. Aluminium alloy 2024 was used as the base matrix material and silicon carbide and fly ash were used as reinforcement particles. Stir casting method was used to prepare the composites. Al-SiC, Al-fly ash, and Al-SiC-fly ash composites of various concentration fabricated. Magnesium was added to increase the wettability. After preparation of composites, microstructure was observed using optical microscopy and X-Ray Diffraction analysis was done to observe the presence of different elements and compounds in the composites. It was found that with an increase in the content of reinforcement density was decreased but tensile strength, yield strength, and hardness were increased. S. Suresh et al. [13] produced aluminium metal matrix composites by taking aluminium alloy Al6061 as Matrix material and TiB_2 particles as a reinforcement material. For the development of the composites stir casting method was used. The main aim of this research was to investigate the effect of TiB_2 in aluminium alloy Al6061. In the experiment, they used different compositions of TiB_2. In testing of mechanical properties such as hardness, strength and also wear characteristics were investigated. Scanning electron microscope was used to investigate the distribution of the TiB_2 in composites. For hardness testing, Vickers hardness tester was used. For the study, the wear behaviour pin on disc tribometer was used. after studying the result it was found that with the increase in the amount of TiB_2 hardness and strength of the material was increased and also with the increase of the amount of TiB_2 wear resistance of material was improved. K. Umanath et al. [14] experimented to investigate the characteristics of the hybrid metal matrix composites. For fabrication purpose aluminium alloy Al6061-T6 was taken as a base material, silicon carbide (SiC) and aluminium oxide (Al_2O_3) were taken as reinforcement materials. the composite was prepared by using stir casting method. silicon carbide and aluminium oxide were taken in equivalent volume fraction. Scanning electron micrograph and x-ray diffractogram were used inspect the distribution of constituents and the distribution was found to be uniform. For conducting the experiment ANOVA technique was used for the design of experiments. The influence of wear testing parameters was investigated and it was observed that all the factors have a significant influence on wear characteristic of these hybrid composites. The increase in the volume fraction of reinforcement led to improving the wear resistance. Chinta Neelima Devi et al. [15] fabricated and evaluated mechanical properties of aluminium-silicon carbide-zinc-copper metal matrix composite. Al6061 alloy was taken as matrix material. Reinforcement materials silicon carbide, zinc and copper were added in different weight proportion. The test for tensile strength, yield stress and % elongation was done on UTM whereas impact test was performed by suing Charpy test and Izod test. It was observed by test results that optimum values zinc and copper are 6 % and 8% for better mechanical properties. V Mani Kumar et al. [16] carried out the study to evaluate mechanical properties of aluminium-copper metal matrix composite. Aluminium alloy al6061 was considered for base material and copper was selected as a reinforcement material. The method of fabrication was die casting process. Copper was added in varying mass fraction. The microstructure study showed the uniform distribution of copper particulates in an aluminium matrix. The observed mechanical properties such as hardness, tensile strength, and impact strength were enhanced with the increased weight % of copper up to 8%. P.B.Pawar et al. [17] prepared aluminium metal matrix composites for the application of spur gear. Aluminium alloy was used as base material and silicon carbide (SiC) was used as a reinforcement material. For fabrication purpose, stir casting technique was used. While preparing composites, silicon carbide was added on the basis of mass ratio. The borax powder was added to increase the wettability of silicon carbide. The microstructure of the composite was studied by optical microscope. Brinell hardness testing machine was used to check the hardness of composites, the results showed that with increasing content of silicon carbide, hardness tends to increase. Theoretical design of spur gear was done by using Lewis formula and Hertz equation. Modelling was done by using CATIA software and finite element analysis was carried out by using ANSYS14.0. Stress distribution In FEA analysis showed that highest value of stress occurred at the tip of the tooth. The application of this composite is to make power transmission element like gears. Bharath V et al. [18] in this study, the purpose was to prepare aluminium metal matrix composite and investigate the mechanical and wear properties. For the study, aluminium alloy Al6061 was considered. For reinforcement, aluminium oxide (Al_2O_3) was considered. The stir casting route was selected for fabrication purpose. The particulate was preheated and mixed with molten metal in 3 steps to achieve the uniform distribution and improve wettability. The microstructure studies were done by using scanning electron micrograph and also x-ray diffraction analysis was done. The distribution was found to be fairly uniform. The test results showed that the hardness and strength (both tensile and yield) increased with increased weight % of Al_2O_3 particulates however ductility was found to be decreased. The wear resistance was also improved with an increase in weight% of reinforcement. Md. Habibur Rahman et al. [19] carried out their study to investigate the microstructure, mechanical properties and wear properties of the aluminium metal matrix composites. Aluminium was selected as the matrix material and silicon carbide was selected as a reinforcement material. Using stir casting method they fabricated composite, silicon carbide was added

in different weight proportions. The microstructure was studied by using an optical microscope, which showed the uniform distribution of the SiC particles. Hardness and tensile strength of the material were increased with increased weight % of SiC particles. The maximum hardness and tensile strength were found with 20% SiC contents in the composite. Similarly, wear resistance was also improved with the addition of the SiC content. Dora Siva Prasad et al. [20] carried out an investigation on the mechanical behaviour of aluminium hybrid composites. In their study, they took the aluminium alloy A356.2 as matrix material. Rice husk ash (RHA) and silicon carbide (SiC) were considered as reinforcement materials. Magnesium was also included as a wetting agent to enhance wettability of reinforcements in the matrix material. Double stir casting process was used to fabricate the composites. The microstructure of composites was studied and it was found to be in uniform distribution. The density and coefficient of thermal expansion (CTE) of composites decreased when weight percentage of reinforcements increased whereas hardness was increased with this change. The ultimate tensile strength and yield strength increased with the increased reinforcement. M.Vamsi Krishna et al. [21] prepared aluminium metal matrix composites and investigated the mechanical properties of the composites. They used Al6061 as matrix material. Silicon carbide and graphite particles were used as reinforcements. Stir casting technique was used for fabrication purpose. During fabrication, magnesium was added to improve the wettability of the reinforcements in the matrix material. After fabrication testing was carried out. SEM analysis was done to investigate the microstructure of the composites and uniform distribution was found in results. In testing results, it was found that the weight fractions of reinforcements have a great influence on mechanical properties of the composites. The tensile strength was increased with increased weight % of the reinforcements. The density increased with SiC alone but the addition of Graphite led to decreased density. K.R.Padmavathi et al. [22] fabricated aluminium metal matrix composites. They used aluminium alloy Al6061 as matrix material. For reinforcement, multiwall carbon nanotubes (MWCNT) and silicon carbide (SiC) were used. the composite was prepared by using ball milling and hot pressing processes. The main purpose of the addition of SiC was to enhance dispersity of reinforcement material in the matrix material. The SEM analysis showed the better dispersion of MWCNTs in composites. The addition of SiC led to a better dispersion of MWCNTs in an aluminium matrix. The hardness of composites was found to be better than the pure aluminium. The author implied the need for a further detailed study to investigate the influence of SiC and MWNCTs on mechanical properties of metal matrix composites. Siddhartha Prabhakar. N et al. [23] carried out a study on preparation of aluminium metal matrix composites and investigated its tribological behaviour. LM14 aluminium alloy was selected as the matrix material and boron carbide (B_4C) particles were selected as a reinforcement material. Taguchi's technique was used design the parameter for the experiment. Stir casting route was used to prepare the composite. The microstructure of composites was studied using an inverted metallurgical microscope and uniform distribution was found. SEM analysis was also carried out to investigate worn out surfaces of composites. Different wear parameters were analyzed to check their influence on wear behaviour of composites. The results showed that with increased sliding velocity and sliding distance, wear behaviour of composites was enhanced, And composites were having good wear resistance at low load. The author suggested the replacement of automotive engine components such as a piston, cylinder liners etc. with these MMCs. Kenneth kanayo Alanene et al. [24] investigated the microstructure characteristics, mechanical properties and wear properties of aluminium matrix hybrid composites. Aluminium alloy 6063 was taken as matrix material for composite preparation. Alumina of various particle sizes, rice husk ash (RHA) and graphite was used as reinforcement materials. The two-step stir casting process was used to produce composites. The microstructure study done by SEM analysis showed the fairly well distribution of reinforcement materials. The test result showed that the hardness decreased with increasing weight proportion of RHA. The tensile strength of composite was improved when graphite was added with RHA, but wear resistance decreased because of graphite addition. Shobhit Jain et al. [25] fabricated and studied the microstructure and mechanical behaviour of aluminium metal matrix composite. Pure aluminium was the matrix material and copper (4%) boron carbide (B_4C) particles were taken as reinforcements. The composites were prepared by powder metallurgy process. The SEM analysis showed the homogeneous distribution of particulates. The tensile and compressive strength increased with increase in B_4C content up to 10% whereas the hardness was found to be directly proportional to the increasing B_4C content. K. Kanthavel et al. [26] studied the tribological properties of the hybrid composite. They took alumina (Al_2O_3) and molybdenum disulphide (MoS_2) as a reinforcement material and pure aluminium as matrix material. The MoS_2 was considered because of its self-lubricating property. The powder metallurgy process was used to fabricate the composites. SEM analysis was done to check the distribution of constituents. And the results showed the uniform distribution of the elements. Wear characteristics of composites were analyzed. The result showed that up to 5 weight % of the MoS_2 is optimum for improving wear resistance. The author suggested that the design of experiments can be changed or extended to analyze and improve

tribological properties of the composites. G. Pitchayyapillai et al. [27] fabricated hybrid metal matrix composite to investigate wear characteristic of the composite. The material selected as a base material was aluminium alloy Al6061. For reinforcements, selected materials were hard ceramic alumina (Al_2O_3) and solid lubricant molybdenum disulphide (MoS_2). The stir casting technique was used to fabricate the composite. The addition of reinforcement was done in different weight %. The wear behaviour was carried out by varying different wear parameters such sliding velocity and applied load. Wear rate increased with the increased load but it was found that wear characteristics of the composite were better than the alloy. The addition of reinforcement led to improvement in wear resistance as well as friction resistance. The mechanical behaviour was also studied found to be increased with increased amount of reinforcement. The result showed that the optimum composition was of MoS_2 as 4 weight % and alumina as 12 weight %. S.C. Prasanna et al. [28] in this paper author prepared aluminium metal matrix composite by aluminium alloy al6061 as matrix material. For reinforcement material, he selected silicon carbide (SiC) along with neem leaf ash and fly ash. The stir casting process was used to fabricate the material. The dispersion of particulates in the matrix was observed by optical and scanning electron micrograph and it was found to be homogeneous distribution. The tensile test performed on universal testing machine and strength of material increased with the inclusion of neem leaf ash. The hardness of the composite tested by using Rockwell hardness tester increased with the increased weight % of reinforcements. Wear test was performed on pin-on-disc tribometer. The wear characteristics of composite improved with the increased weight % of the reinforcement constituents.A. Manikandan et al. [29] fabricated and studied the hardness and tensile properties of the aluminium metal matrix composites used for the application of piston. They selected the al6061 alloy as matrix material. Silicon carbide, aluminium oxide along with zirconium oxide were added as reinforcement material to enhance the strength of piston material. The material was fabricated by using stir casting method. The reinforcement materials were added in steps in different compositions of weight. The hardness was tested by Vickers hardness testing machine. The result concluded that addition of reinforcement led to increased mechanical properties of the composites as compared to the base material. A.A. Agbeleye et al. [30] carried out a study to investigate mechanical properties as well as wear characteristics of aluminium matrix composites for brake pad application. Aluminium alloy 6063 was taken as a base material and aluminosilicate clay particles were used as a reinforcement material. The stir casting route was used to fabricate the composites. The author studied the effect of various weight fraction of clay on properties of the material and compared the result with the existing brake pad material semimetallic brake pad. The hardness (measured by using Vickers hardness tester) and tensile strength of material increased with increased weight % of clay up to 15%, after that it started to decrease. The similar effects experienced in wear behaviour where wear resistance increased up to 15 weight % of the clay. The distribution of particles was uniform in the matrix.

III. CONLUSION AND FUTURE WORK DIRECTIONS

By the review of these paper, it was observed that every reinforcement that is being mixed with a matrix material, their particles size, the amount is being mixed have an effect on the different mechanical, tribological properties. It can be concluded that-

- Addition of particulates up to some weight percentage is helpful in increasing the mechanical and wear properties, but the reinforcements size also affects the properties.
- The wear properties depend on the sliding speed, applied load etc.
- Most widely used methods for fabrication are stir casting and powder metallurgy because of the inexpensive coast and easy to operate.
- Mechanical properties such as tensile strength, hardness, toughness, yield strength etc. increased with the increased weight percentage of reinforcements.

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