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Fabrication of Aluminum Based MMC Using Silicon Carbide Reinforcement and Evaluation of Mechanical Properties: A Review

Baljeet Singh
School of Mechanical Engineering
Lovely Professional University. Phagwara, Punjab,
India

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

Keywords— AluminumMMC, reinforcement; stir casting; alumina; silicon carbide

I.Introduction

A composite material is synthesized by integrating two or more materials/metals which are having different but highermechanical properties. These materials combine together to give the composite its unique capabilities. In a composite different reinforcement do not dissolve or blend into each other. In composites, one of the materials in minor proportion known as reinforcing phasecan be in the form of fibers or particles embedded in the matrix phase which is in major proportion.Usually, fibers and particulateshave low densities while the matrix is usually softand tougher.

Composite materials arewidely used in the areas of scientific and applied research for many years; still in the past decade they have been recognized as engineering materials. At presentthey have made remarkable progress and advances in mechanical properties. The primaryprosare inculcation of the properties of both, i.e metal matrix and reinforcements.This helps in synthesis ofa material with properties which canmeet specific requirements in many fields. Most of the work has been dealt withaluminum and other light metal matrices. These metalsare lightweight and possesses high strength and stiffness. However,synthesis offiber reinforced Al matrix composites is founddifficult. Today, main focus is todecrease the cost, develop mass production techniques. AMMC is a composite material contains two or more sub parts, one is primarily metal and the other material is ceramic.Ifthere are at least three constituentsthen it is known as hybrid composite.

There are many prosof MMCs as compared to monolithic metals. Notably, higherthermalproperties, lower thermal conductivity, high hardness and high specific strength. Because of these characteristics, MMCs areconsidered for a variety of applications. On the other hand, theimpact strength of MMCs is less than monolithic metals and they are more costly also. If we compare it with polymer matrix composites, MMCs have higher properties, likehigher compressive strength and high-temperature properties. There are also other prosof MMCs like notremarkable moisture absorption, flammability, high electrical and thermal coefficients.MMC reinforcements can be classified into five major categories: Particulates, continuous and discontinuous fibers, whiskers and particulates. Usually the reinforcements are ceramics like oxides, carbides, and nitrides. They havesuperior combinations of specific strength and stiffness at room and elevated temperatures.

Aluminum and titanium are the most widely used MMC. These metals are available in various alloy combinations and further have comparably low specific gravities.Likewise, magnesium is even lighter, but its great affinity for oxygen promotes atmospheric corrosion, which thereby restricts its use for many applications. Beryllium is also light but its brittleness prevents its much use. Nickel and cobalt-based alloys have the problem of oxidation of fibers in high temperature applications.

The methods of producing MMCs are Solid state methods, Liquid state methods. Solid state method includes PM and Stir casting, squeeze casting, spray deposition comes under liquid state methods. The work is mainly focused on stir casting process to understand the way to get a homogeneous mixture of particulates, reinforcements in the matrix.

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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 aluminumMMC and some of the relevant are as follows:

Z.Z. Chen etal.[1] studied the outcome of particle size on fatigue crack initiation and crack growth in aluminum matrix composites. Aluminum alloy 2024 was taken into consideration for inspect. Silicon carbide (SiC) was taken in different sizes (5 µm, 10 µm, 60µm) for reinforcement. The material was processed by using PM process. Fully reversed axial fatigue tests were executed using electro servohydraulic fatigue testing machine. Materila characterization was done using Scanning electron microscopy and optical microscope to inspect the crack growth path and fracture surface of the sample.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 inspect on Aluminum alloy (AL6061) - Silicon Carbide (SiC) and Aluminum alloy (Al7075)- Alumina (Al_2O_3) MMC for analyzing the mechanical and tribological properties and compared them. The liquid metallurgy technique (stir casting) was used to synthesis the MMC. The different weight percentage of reinforced material were used while fabricating the samples for testing. The microstructuresillustrated the homogeneous distribution of the reinforced particles in the matrix. The strength of the composites was found to be higher than base material and also Al6061-SiC illustratedhigherstrength properties than that of Al7075Al_2O_3. Hardness was found to be increasing with the improve in weight percentage of the reinforced particles. The wear resistance properties of composites were improved and also wear resistance of Al6061-SiC was higher than the alloy. N. Radhika et al. [3] studied the tribological properties of MMC of aluminum alloy (Al-Si10Mg) reinforced with alumina and graphite and also the outcome of wear parameters like sliding distance, sliding speed and applied on the dry sliding behaviour of Al/Al_2O_3/Gr discovered. Taguchi method was used for generating the design of experiments and for examination of parameters ANOVA technique was used. The liquid metallurgy route was used for fabrication of MMC. 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 illustrated that the sliding distance has the greater outcome on rate of wear and applied load has also a very remarkableoutcome on rate of wear and sliding speed has a lesser outcome on rate of wear. A.R.I. Khedar et al. [4] synthesizedaluminumMMC by taking pure aluminum 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 adapted to develop 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 refinement 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 enhanced mechanical properties such as hardness, 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-YeolJeong [5] discovered the outcome of alloying elements on the mechanical properties on Aluminum – Silicon alloys used for the piston. Casting alloys were synthesized 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. Ni and Cu addition results in finer microstructure and homogeneous precipitation. The mechanical properties were improved with an improve in Cu and Ni content and Also creep properties were enhancedremarkablely with increasing of Ni and Cu content. G. G. Sozhamannan et al. [6] studied the outcome of factors of stir casting process on aluminumMMCs. They discovered the outcome of factors such as holding time and processing temperature on homogeneous distribution of reinforced particles and also on mechanical properties such as ductility, hardness, tensile and impact behaviour. Al11Si-Mg alloy used as the matrix. 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 homogeneous distribution was found 750 ^{0}C and 800 ^{0}C. Strength and hardness were found to be increasing with the processing temperature up to 800℃ and with the improve in holding time ultimate strength was found to be decreasing. S. Rama Rao and G. Padmanabhan [7] synthesizedaluminum- boron carbide composite and examined 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 discovered was homogeneous. Hardness and ultimate compression strength were found to be increasing with the improve in the amount of boron carbide particles. Density was decreased with improve in the amount of reinforcement particles. T. Rajmohan et al. [8] evaluated the wear and mechanical properties of hybrid MMCs. As a matrix, Al356 alloy was used. Silicon carbide and mica were used as reinforcement materials. The stir casting method was used to synthesis the composites. The particulates were preheated before introducing to molten metal in the crucible. The microstructure studied by SEM micrograph was noticeably homogeneous. The chemical composition was to explored by energy dispersive X-ray (EDX). The optimum result was found at 10% silicon carbide and 3% mica. With enhanced reinforcement wear characteristics were improved. Dinesh M. Pargundeet al.[9] experimentally discovered the properties of aluminum – silicon carbide MMCs. The stir casting method was used for fabrication of composites. Silicon carbide was used in different weight percentage with aluminum alloy. Tests for Hardness, impact strength, microstructure, and corrosion were carried out and it was discovered that hardness,densityand impact strength was enhanced with the improve in weight percentage of silicon carbide, and corrosion rate was found to be satisfactory. Faiz Ahmad et al. [10] attempted to inspect the wear characteristics of the aluminumMMC and also to explored about brake disc material. Aluminum alloy 242 was taken as the matrix and reinforced with alumina particles. Composite was processed by the squeeze casting process. SEM examination was carried out to inspect the surface of test samples. Wear testing of composites and brake disc was done and the results were compared. The test results illustrated a different type of wear such as adhesive, fatigue and abrasive type were experienced by test samples. With the enhanced sliding speed, the coefficient of friction decreased and wear resistance enhanced and for composites, the results were higher than brake disc material. Sudindra S et al. [11] experimentally carried out the inspect on aluminumMMCs. Aluminum 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 discovered that with the addition of Al_2O_3 alone improves hardness and strength and decreased rate of wear.The addition of graphite particulates alone decreases hardness and enhanced ductility but the cumulative outcome resulted in decreased rate of wear and enhancedstrength. MahendraBoopathi M et al. [12] evaluated the mechanical properties of the hybrid MMCs. Aluminum alloy 2024 was used as the base matrix 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 synthesized. Magnesium was added to improve the wettability. After preparation of composites, microstructure was discovered using optical microscopy and X-Ray characterization was done for estimation of different elements and compounds in the composites. It was found that with an improve in the content of reinforcement density was decreased but strength, yield strength, and hardness were enhanced. S. Suresh et al. [13] produced aluminumMMCs by taking aluminum alloy Al6061 as Matrix and TiB_2 particles as a reinforcement material. For the synthesis of the composites stir casting method was used. The main aim of this research was to to explore the outcome of TiB_2 in aluminum 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 to explored. Scanning electron microscope was used to to explore the distribution of the TiB_2 in composites. For hardness testing, Vickers hardness tester was used. For the inspect, the wear behaviour pin on disc tribometer was used. after inspecting the result, it was found that with the improve in the amount of TiB_2 hardness and strength of the material was enhanced and also with the improve of the amount of TiB_2 wear resistance of material was improved. K. Umanath et al. [14] experimented to to explore the characteristics of the hybrid MMCs. For fabrication purpose aluminum alloy Al6061-T6 was taken as a base material, silicon carbide (SiC) and aluminum oxide (Al_2O_3) were taken as reinforcement materials. the composite was processed by using stir casting method. silicon carbide and aluminum 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 homogeneous. For conducting the experiment

ANOVA technique was used for the design of experiments. The outcome of wear testing parameters was to explored and it was discovered that all the factors have a remarkableoutcome on wear characteristic of these hybrid composites. The improve in the volume fraction of reinforcement led to improving the wear resistance. ChintaNeelima Devi et al. [15] synthesized and evaluated mechanical properties of aluminum-silicon carbide-zinc-copper MMC. Al6061 alloy was taken as matrix. Reinforcement materials silicon carbide, zinc and copper were added in different weight proportion. The test for strength, yield stress and % elongation was done on UTM whereas impact test was executed by suing Charpy test and Izod test. It was discovered by test results that optimum values zinc and copper are 6 % and 8% for higher mechanical properties. V Mani Kumar et al. [16] carried out the inspect to evaluate mechanical properties of aluminum-copper MMC. Aluminum 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 microstructuresillustrated the homogeneous distribution of copper particulates in an aluminum matrix. The discovered mechanical properties such as hardness, strength, and impact strength were enhanced with the enhanced weight % of copper up to 8%. P.B.Pawar et al. [17] processedaluminumMMCs for the application of spur gear. Aluminum 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 improve 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 illustrated that with increasing content of silicon carbide, hardness tends to improve. Theoretical design of spur gear was done by using Lewis formula and Hertz equation. Modelling was done by using CATIA software and finite element examination was carried out by using ANSYS14.0. Stress distribution In FEA examinationillustrated 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 inspect, the purpose was to prepare aluminumMMC and to explore the mechanical and wear properties. For the inspect, aluminum alloy Al6061 was considered. For reinforcement, aluminum 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 homogeneous distribution and improve wettability. The microstructure studies were done by using scanning electron micrograph and also x-ray diffraction examination was done. The distribution was found to be fairly homogeneous. The test results illustrated that the hardness and strength (both tensile and yield) enhanced with enhanced weight % of Al_2O_3 particulates however ductility was found to be decreased. The wear resistance was also improved with an improve in weight% of reinforcement. Md. Habibur Rahman et al. [19] carried out toinspectand explore the microstructure, mechanical properties and wear properties of the aluminumMMCs. Aluminum was selected as the matrix and silicon carbide was selected as a reinforcement material. Using stir casting route, they synthesized composite, silicon carbide was added in different weight proportions. The microstructure was studied by using an optical microscope, which illustrated the homogeneous distribution of the SiC particles. Hardness and strength of the material were enhanced with enhanced weight % of SiC particles. The maximum hardness and 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 aluminum hybrid composites. In examination, they took the aluminum alloy A356.2 as matrix, 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. Double stir casting process was used to synthesis the composites. The microstructure of composites was studied and it was found to be in homogeneous distribution. The density and coefficient of thermal expansion (CTE) of composites decreased when weight percentage of reinforcements enhanced whereas hardness was enhanced with this change. The ultimate strength and yield strength enhanced with the enhanced reinforcement. M.Vamsi Krishna et al. [21] processedaluminumMMCs and to explored the mechanical properties of the composites. They used Al6061 as matrix. 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. After fabrication testing was carried out. SEM examination was done to to explore the microstructure of the composites and homogeneous distribution was found in results. In testing results, it was found that the weight fractions of reinforcements have a great outcome on mechanical properties of the composites. The strength was enhanced with enhanced weight % of the reinforcements. The density enhanced with SiC alone but the addition of

Graphite led to decreased density. K.R.Padmavathi et al. [22] synthesizedaluminumMMCs. They used aluminum alloy Al6061 as matrix. For reinforcement, multiwall carbon nanotubes (MWCNT) and silicon carbide (SiC) were used. the composite was processed 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. The SEM examinationillustrated the higher dispersion of MWCNTs in composites. The addition of SiC led to a higher dispersion of MWCNTs in an aluminum matrix. The hardness of composites was found to be higher than the pure aluminum. The author implied the need for a further detailed inspect to to explorethe outcome of SiC and MWNCTs on mechanical properties of MMCs. Siddhartha Prabhakar. N et al. [23] carried out a inspect on preparation of aluminumMMCs and to explored its tribological behaviour. LM14 aluminum alloy was selected as the matrix 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 homogeneous distribution was found. SEM examination was also carried out to to explore worn out surfaces of composites. Different wear parameters were examined to check their outcome on wear behaviour of composites. The results illustrated that with enhanced 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 kanayoAlanene et al. [24] to explored the microstructure characteristics, mechanical properties and wear properties of aluminum matrix hybrid composites. Aluminum alloy 6063 was taken as matrix 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 inspection done by SEM examinationillustrated the fairly well distribution of reinforcement materials. The test result illustrated that the hardness decreased with increasing weight proportion of RHA. The strength of composite was improved when graphite was added with RHA, but wear resistance decreased because of graphite addition. Shobhit Jain et al. [25] synthesized and studied the microstructure and mechanical behaviour of aluminumMMC. Pure aluminum was the matrix and copper (4%) boron carbide (B_4C) particles were taken as reinforcements. The composites were processed by PM process. The SEM examinationillustrated the homogeneous distribution of particulates. The tensile and compressive strength enhanced with improve 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 aluminum as matrix. The MoS_2 was considered because of its self-lubricating property. The PM process was used to synthesis the composites. SEM examination was done to check the distribution of constituents. And the results illustrated the homogeneous distribution of the elements. Wear characteristics of composites were examined. The result illustrated 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] synthesized hybrid MMC to to explore wear characteristic of the composite. The material selected as a base material was aluminum 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 synthesis 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. Rate of wearenhanced with the enhanced load but it was found that wear characteristics of the composite were higher than the alloy. The addition of reinforcement led to refinement in wear resistance as well as friction resistance. The mechanical behaviour was also studied found to be enhanced with enhanced amount of reinforcement. The result illustrated 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 processedaluminumMMC by aluminum alloy al6061 as matrix. For reinforcement material, he selected silicon carbide (SiC) along with neem leaf ash and fly ash. The stir casting process was used to synthesis the material. The dispersion of particulates in the matrix was discovered by optical and scanning electron micrograph and it was found to be homogeneous distribution. The tensile test executed on universal testing machine and strength of material enhanced with the inclusion of neem leaf ash. The hardness of the composite tested by using Rockwell hardness tester enhanced with the enhanced weight % of reinforcements. Wear test was executed on pinon-disc tribometer. The wear characteristics of composite improved with the enhanced weight % of the reinforcement constituents.A. Manikandan et al. [29] synthesized and studied the

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hardness and tensile properties of the aluminumMMCs used for the application of piston. They selected the al6061 alloy as matrix. Silicon carbide, aluminum oxide along with zirconium oxide were added as reinforcement material to enhance the strength of piston material. The material was synthesized 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 enhanced mechanical properties of the composites as compared to the base material. A.A. Agbeleye et al. [30] carried out a inspect to to explore mechanical properties as well as wear characteristics of aluminum matrix composites for brake pad application. Aluminum 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 synthesis the composites. The author studied the outcome 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 strength of material enhanced with enhanced weight % of clay up to 15%, after that it started to decrease. The similar outcomes experienced in wear behaviour where wear resistance enhanced up to 15 weight % of the clay. The distribution of particles was homogeneous in the matrix.

III.CONLUSION AND FUTURE WORK DIRECTIONS

By the review of these paper, it was discovered that every reinforcement that is being mixed with a matrix, their particles size, the amount is being mixed have an outcome 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 PM because of the inexpensive coast and easy to operate.
- Mechanical properties such as strength, hardness, impact strength, yield strength etc. enhanced with the enhanced weight percentage of reinforcements.

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