A Review on Fabrication and Characterization of Aluminium Metal Matrix Composite (AMMC)

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Abstract

The trend towards the use of composites is increasing rapidly in the ongoing scenario and is likely to increase more rapidly in the future. Nowadays aluminium and its alloy based composites are gaining importance in the upcoming fields of engineering. Aluminium metal matrix composite (AMMC) possess superior strength, hardness, corrosion resistance, fatigue and creep resistance in addition to low weight advantage of aluminium. Aluminium based composites (AMMC) are widely used in aerospace and automotive industries due to high strength to wear ratio. Mechanical Components due to insufficient strength fails under various types of loading. Modern mechanical components require advance properties, the material available in pure form do not possess the required strength, hardness, corrosion resistance etc. A Composite is formed by combination of two or more physically and chemically distinct substances and is fabricated to enhance the characteristics of base metal. The material is then characterized by the different types of analysis like tensile, impact, hardness, along with thermal analysis such as XRD and DTA. Metal matrix composite (MMC) are formed when the base metal is metal and reinforcement takes place in the form of powder, particles, fibers and whiskers. Reinforcements in the metal matrix composite may be a metal or other material which may be ceramic or any other organic compound. Metal matrix composites (MMC) possess significantly enhanced properties which improve the functioning as well as service life of the various mechanical components. This paper is aimed to review the theory, experiments and methodology to fabricate aluminium metal matrix composites (AMMC) and also the characterization of fabricated material.

1. Introduction

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and having bulk properties significantly different from those of any of the constituents. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical property of steel are similar to those of pure iron) . Favorable properties of composites materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

Composite materials have been used for advanced structural and non-structural applications in automotive, aircraft, marine and electrical industries. The metal matrix composites (MMCs) consist of reinforcing materials and metal matrices such as aluminum, titanium, steel to obtain new materials with good mechanical properties such as high stiffness, strength and high temperature resistance. In recent years, SiCp- Al MMCs have received significant attention and their fabrication techniques have been the major interest, which affect the mechanical properties of the composites. [2]

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Among various discontinuous dispersoids used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. It is therefore expected that the incorporation of fly ash particles in aluminium alloy will promote yet another use of this low-cost waste by-product and, at the same time, has the potential for conserving energy intensive aluminium and thereby, reducing the cost of aluminium products .[7]

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Now a days the particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components. Cast aluminium matrix particle reinforced composites have higher specific strength, specific modulus and good wear. The present paper discusses about stir casting process and various research conducted on it for the manufacturing of MMC's.

2. Manufacturing of MMC's

Stir casting method of fabrication of MMC's. Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost effective method of liquid state fabrication is Stir Casting. Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies. [12]

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape or form (compacting), and then heating the compressed material in a controlled atmosphere to bond the material (sintering). The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting, and sintering. Compacting is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at atmospheric pressure. Optional secondary processing often follows to obtain special properties or enhanced precision. The use of powder metal technology bypasses the need to manufacture the resulting products by metal removal processes, thereby reducing costs. The aluminum powder (purity of 99.0%, grain size of 70μm) and CNTs were homogeneously mixed by hand grinding for 30min, and ethanol was added to avoid possible oxidation. The mixture of CNTs and aluminum powder was uniaxially pressed in steel dies under a pressure of 300MPa for 2 min. [10]

3. Studies of MMC's

Madhumita Goswami et al. in 2000 demonstrated in their study the Synthesis of machinable quality magnesium aluminium silicate (MgO–Al2O3–SiO2) for fabrication of insulators/spacers usable in high voltage applications under high vacuum conditions has been carried out following two different routes i.e. (i) sintering route, and (ii) glass route. MAS glass ceramic samples were prepared following sintering as well as glass routes using three-stage schedules involving calcination, nucleation and crystallization processes. They were then sintered using a two-step heating programme. In the first step, the compact was heated up to ~ 600 to 630°C for 2–4 h to ensure good nucleation and to initiate crystal growth. In the second step, heating was carried out with different heating rates in the range of 15–60°C/h up to crystallization the sintering temperatures of 950–1070°C. The variation of density with sintering temperature for MAS glass ceramic prepared by sintering route is shown in figure1.

We have obtained machinable quality magnesium aluminium silicate glass ceramics by two processes (i.e. sintering and glass routes). Initial results on the material produced by glass route are found to give better surface finish, less porosity, higher density and electrical break-down strength compared to those prepared by sintered method. However, both types of samples show suitability for UHV and high voltage applications. More detailed studies are needed to be done on the samples prepared by glass route to exploit their superior properties. [1]

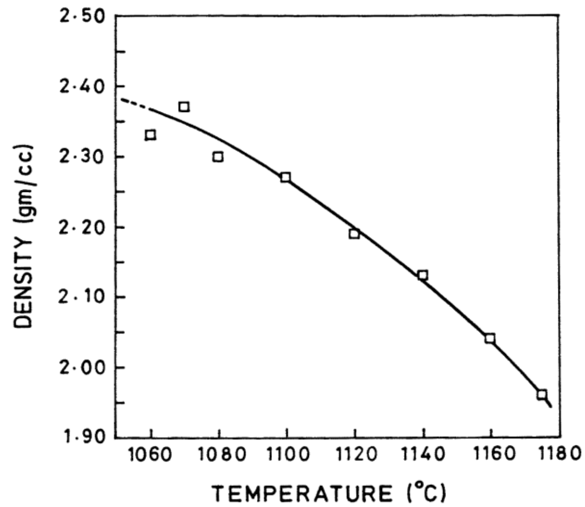

Fig: 1. variation of density with sintering temperature for MAS glass ceramic prepared by sintering route [1]

Mattika Bunma et al. in 2011 investigated Process Parameter-Microstructure-Mechanical Property Relations of SiCp- Reinforced Aluminum Composites Produced by Powder-Injection Casting. This research shows the effects of process parameters, which are argon gas flow rates at 5 and 10 l/min, and casting temperatures at 620 and 680°C, on integrity of the SiCp-reinforced 356 aluminum composites fabricated by powder-injection casting using a modified flux injection degassing machine. The SiCp additions are 0, 10 and 15 wt. %. In this experiment Aluminum 356 alloy was melted at 700oC and injected with preheat-treated SiCp at 590°C. This was carried out via the argon gas for 15 minutes at a rotational speed of 1000 rpm using the modified SiCp injection degassing machine. The microstructure and mechanical property were investigated. Experimental results showed that unreinforced alloy gave minimum % internal void whereas the addition of SiCp increased tendency of porosity formation. It also states that Higher Ar gas flow rate at 10l/ min provides undesirable disturbance in molten mixture, causing large SiCp- gas porosity clustering, which results in degraded density and hardness. The Low casting temperature at 620 ºC provides inferior properties of the composites due to high degree of porosity as a result of highly viscous melt to limit metal feeding and effective degassing. Following graph depicts the Porosity of composite in terms of % internal voids. [2]

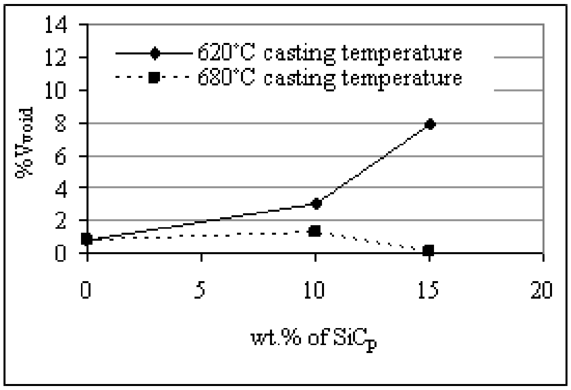

Fig: 2. Ar gas flow rate = 5 l/min [2]

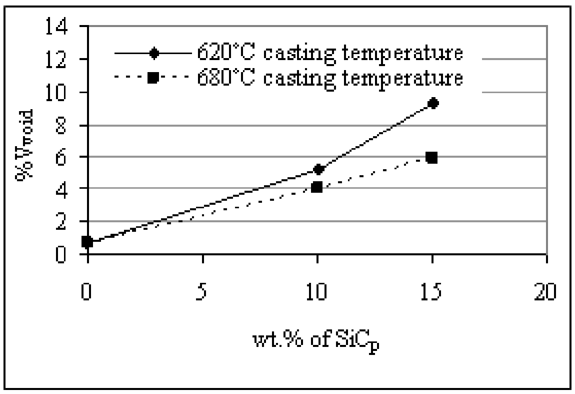

Fig: 3. Ar gas flow rate = 10 l/min [2]

Madhu Kumar YC et al. in 2012 evaluated the mechanical properties of Aluminium Alloy (6061) matrix composites (AMCs) reinforced with 3 to 12 wt% glass particulates of 75μm, 88μm, 105μm and 250μm using stir casting route. Aluminium alloy in the form of ingots was heated at the temperature 740°C. Cover flux is added to reduce oxidation. 3g of C_2Cl_6 was added to each 0.25Kg of aluminium alloy in form of degassing tablet at a temperature of 700^0C. Preheated glass particles at 300^0C are added into melt and stirred for 5 min. Dispersion of particles was achieved according sintering route. The experiment concluded that the tensile strength and hardness increases by adding reinforcement up to 9% and then decreases with increase with wt% of glass particles. Microstructural observations show that the glass particulates are uniformly distributed in the Al6061 matrix. [3]

S. Rama Rao et al. in 2012 investigated Fabrication and mechanical properties of aluminum-boron carbide composites. The aluminum-boron carbide composites were fabricated by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5%). X-ray diffraction was used to identify the phase of composite. The experiment concluded that the aluminium alloy composites containing different amounts of boron carbide particles were produced by stir casting method successfully. It also states that Uniform distribution of the boron carbide particles in the matrix phase was obtained. The hardness of the composites increased and density was decreased with increasing the amount of the boron carbide in the matrix phase. Increasing the amount of boron carbide particles in composites caused the ultimate compression strength to increase. [4]

Sourabh Gargatte et al.in 2012 investigated that the Preparation & Characterization of Al-5083 Alloy Composites and reinforced with SiC particles fabricated by stir casting technique. Different volume fraction of SiC particles (3, 5 and 7 wt%) were used for synthesis. The wear test has been conducted on pin-on-disc testing machine to examine the wear behaviour of the alu-minium alloy and its composites. The DRAMMC material selected for the present investi- gation was based on Al-Mg matrix alloy, designated as aluminium association as AA 5083. Figure 4 shows the melt- ing and stirring mechanism and CI permanent moulds. Analysis of variance was performed using statistical software "MINITAB R15". ANOVA has been carried out to analyze the influence of wear parameter, Sliding speed, Load, Sliding distance and Weight per-centage of SiC particles. The analysis was carried out for a level of significance of 5% (i.e. the level of confidence 95%). The ANOVA has resulted in zero degree of freedom for error term, it is necessary to pool the factor having less influence, for correct interpretation of results.he found that the a General regression mathematical model has been successfully developed to predict the wear rate of AA5083-SiC particle composite. The developed model can be effectively used to predict the wear rate of composite at 95% confidence level within the range of investigation. The wear rate decreased for in-creasing the reinforcement percentage of SiC particles. Al-5083 reinforced with 3, 5 & 7 wt pct shows lesser wear rate compared with pure Al-5083 alloy.The hardness of Al-5083 increased considerably with increase in SiC particles up to 7 wt%. [5]

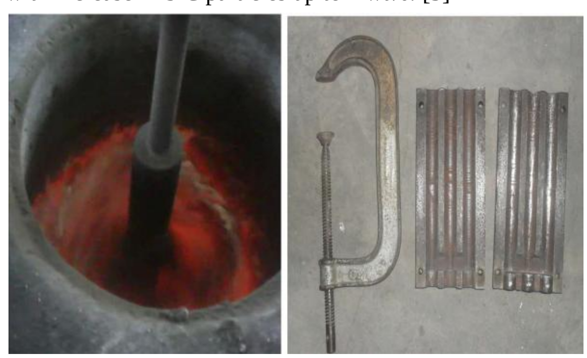

Fig: 4. Preparation of Al-5083 composite & CI permanent mould [5]

Abhishek Kumar et al. in 2013 investigated the properties of A359/Al2O3 metal matrix Composite fabricated by the process using electromagnetic stir casting method. In electromagnetic stir casting a selected matrix metal is heated and reinforcement material is dispersed in the melt. The reinforced material is rotated continuously by electromagnetic field till solidification occurs. It helps to incorporate reinforcement particles into the alloy matrix keeping MMC slurry in semisolid state. Metal composite was fabricated in the Muffle Furnace in the range of 730±20 ◦C. The melt was stirred at 300rpm using a 3 phase induction motor on the addition of Al2o3 particles. The experiment includes varying weight percentage from 2% to 8% in steps of 2% and the mechanical properties are compared with un-reinforced A359 matrix alloy. They investigated the hardness and tensile strength of A359/Al2O3 metal matrix Composite. They suggested that trend of hardness increases with the increase in weight percentage of Al2O3 particles in A359. The result is shown in the table.1. [6]

Table: 1. Hardness of the MMCs A359/Al2O3 at different %

Material	A359	$A359/Al_2O_3$ 2.0wt.%	$A359/Al_2O_3$ 4.0wt.%	$A359/Al_2O_3$ 6.0wt.%	$A359/Al_2O_3$ 8.0wt.%
Hardness (HRC)	46	51.5	58.4	66.7	72.8

Experiment shows that the tensile strength of the as cast MMCs produced is somewhat higher than that of the non-reinforced A359 alloy. They also concluded that Electromagnetic stirring action produces cast MMC with smaller grain size and there is a good particulate matrix interface bonding. [6]

Mahendra Boopathi et al. in 2013 investigated that evaluation of the physical properties of Aluminium 2024 in the presence of silicon carbide, fly ash and its combinations. Consequently aluminium metal matrix composite combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material forced with silicon carbide and fly ash hybrid metal matrix composites In the presence of silicon carbide and fly ash [SiC (5%) + fly ash (10%) and fly ash (10%) + SiC (10%)] with aluminium The compositions were added up to the ultimate level and stir casting method was used for the fabrication of aluminium metal matrix composites. The matrix material used in the present investigation was pure aluminium. Aluminium was purchased from Perfect Metal Works, Bangaluru, Karnataka, India. Silicon carbide, fly ash and magnesium were commercially available. In this study, the aluminium-SiC, aluminum- fly ash, aluminium-SiC-fly ash and aluminium-fly ash-SiC metal matrix hybrid composite was prepared by stir casting route (Fig. 5). Pure aluminum was melted in a resistance furnace. The melt temperature was raised up to 720°C and then the melt was stirred with the help of a mild steel turbine stirrer. The stirring was maintained between 5 to 7 min at an impeller speed of 200 rpm. To increase the wettability, 1.5% of pure Mg was added with all composites. The melt temperature was maintained 700°C during addition of Mg, SiC, fly ash, SiC-fly ash mixture particles. The dispersion of fly ash and other particles were achieved by the vortex method. The melt with reinforced particulates were poured into the preheated permanent metallic mold. The pouring temperature was maintained at 680ºC. The melt was then allowed to solidify in the mould. He had found that the tensile strength of composites is higher than that obtained for the unreinforced Al. Density of the composites decreased by increasing the content of the reinforcement. Hence, it was found that, instead of Al-SiC and Al-fly ash composites, Al-SiC-fly ash composites show better performance. So these composites can be used in applications where to a great extent weight reductions are desirable Tensile strength, yield strength and hardness were determined for the test materials. Increase in area fraction of reinforcement in matrix result in improvedtensile strength, yield strength and hardness With the addition of SiC and fly ash with higher percentage the rate of elongation of the hybrid MMCs is decreased significantly Optical micrographs revealed that both the SiC and flay ash particles are well distributed in aluminium matrix.[7].

Fig: 5. Stir Casting Unit [7]

G. B. Veeresh Kumar et al. in 2011 investigated Mechanical and Tribological Behavior of Particulate Reinforced Aluminum AL6060 & AL7075 Metal Matrix Composites.He was observed the aspects of mechanical and wear behavior of Al-MMCs and the prediction of the Mechanical and tribological properties of Aluminum MMCs. The Al6061-SiC and Al7075-Al2O3 particulate reinforced composites were developed by liquid metallurgy technique (stir casting route). The cast alloy and composite specimens were subjected to density test by two methods, i.e. weight to volume ratio and another being the rule of mixture, He concluded that the ceramic reinforced Al-MMCs will have better wear resistance than the unreinforced alloys [8].

Jagesvar Verma et al. in 2012 investigated that Processing of 5083 Aluminum Alloy Reinforced with Alumina through Microwave Sintering. Metal matrix composite is an important class of materials with high potential for struc- tural applications requiring high specific modulus, strength and toughness. Metal matrix composites with unique pro- perties are growing every day and widely used in different industries because of their high mechanical properties and wear resistance. Aluminium MMC shows poor strength which can be improved by adding some alloying elements like Cu, Mg, Si and Zn. Al5083 alloy and alumina as reinforcement in various weight percentages by powder metallurgy route (e.g. high energy ball milling), hot com- paction, and microwave heating. Powder metallurgy me- thod is the most suitable method for making metal matrix composites. The alumina (Al2O3) powders were mixed in different composition with 5083Al by four point planetary ball mill. Four different sets of metal matrix composites were prepared. They observed that the solid solution of solute in Al during mechanically alloying was determined by XRD. Powder morphology and size become uniform i.e. all powder partials were regular shape with narrow size distribution. Microwave sintering of mechanically alloyed Al5083 alloy and composites resulted in good density, i.e. 97% of theoretical density. The effect of alumina in 5083 alloy was studied with respect to hardness value .There was a trend that hardness value increased with increase alumina content. The wear rate was low with increasing alumina content. Aluminium 5083 alloy and composite give good response to microwave.

Shadakshari R et al. in 2012 investigated that Carbon Nanotube Reinforced Aluminium Matrix Composites mixing procedures for 2024Al-CNTs powder preparation alongside depiction of the CNTs dispersion results from the different mixing techniques. Based on the geometry and physical properties of multiwalled nanotubes, three strengthening mechanisms were considered for CNT/Al composite system. The investigation of the damping behaviour of 2024Al-CNT composite showed that the damping capacity of the composite with a frequency of 0.5 Hz reaches 975 x 10-3, and the storage modulus is 82.3 GPa when the temperature is 400˚ C, which shows that CNTs are a promising reinforcement for metal matrix composites to obtain high damping capabilities at an elevated temperature without sacrificing the mechanical strength and stiffness of a metal matrix. Powder Metallurgy: The aluminum powder (purity of 99.0%, grain size of 70μm) and CNTs were homogeneously mixed by hand grinding for 30min, and ethanol was added to avoid possible oxidation. The mixture of CNTs and aluminum powder was uniaxially pressed in steel dies under a pressure of 300MPa for 2 min. The specimens were isothermally sintered at 100˚C for 1 h and 600˚C for 2 h in a pure argon atmosphere. The specimens for testing, containing 0 to 3% of CNTs respectively, were 60 mm X 10 mm X 2 mm in size. They found that Ball milled samples containing CNTs exhibited high notch sensitivity and consistently fractured outside the gauge length. It is shown that a proper mechanical interaction between aluminum particles and Ni-P-CNT composite coating has been achieved. It is also evident that the coating has increased the average size of the aluminum particles. The HPT processed disk was composed of considerably equilibrium grain boundaries with high misorientaiton angles. The CNT–reinforced ultrafine grained microstructural features resulted in high strength and ductility. The strengthening of the composite could be due to the synergistic effect of mechanisms thermal mismatch, Orowan looping and shear lag models. [10].

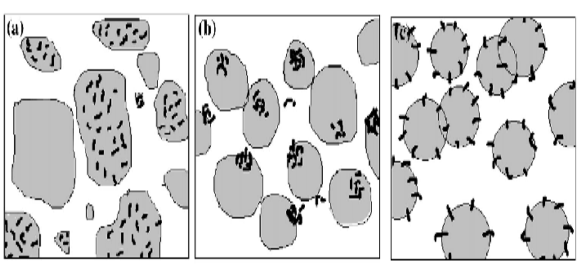

Fig: 6. Schematic depictions of CNTs and Al powder after different mixing techniques. In (a) high energy ball milling, CNTs were effectively dispersed though insufficiently distributed within the Al powders; and in (b) low energy ball milling, CNTs dispersed within Al powder though agglomerates still existed; and in (c) the PBA method, CNTs were coated with Al powders though agglomerates still existed. [10]

G. Shaik usmansha et al. in 2013 he study about the Production And Tribological Characterization Of Stir-Cast Hybrid Composite Aluminium 6061 Reinforced with Sic and Ti. The ratio of particulates based on weight percentage such as (2.5%, 5%, 7.5% and 10%) both SiC and Ti. The composite is developed by stir casting method. The particle size of SiC and Ti between 16 to 22 μm. Metal matrix composites are basically produced either by Liquid Metallurgy Route or Powder Metallurgy. In LMR the reinforcement’s phases are mechanically dispersed in the matrix phase. Stir casting method is mostly used because components at a normal cost. The stir casting technique increases the microstructure and reduces porosity. he found tha The uniform distribution of the particles was get in the Al6061/10 wt. % Ti and SiC cast at stirring speed of 600 rpm as compared to the other composites. From optical microscope is observed in the 6061 Al alloy matrix and 10 wt. % SiC and Ti reinforcements act as a good bonding. Hybrid composites showed high hardness as compared to unreinforced alloy due to hard phase silicon carbide and Titanium particulates bonded uniformly in aluminum 6061 based matrix. Hybrid composite sample with 10wt. % SiC and Ti composition have better tribological properties. The reinforcement of Al 6061 alloy with SiC and Ti particulates up to a volume fraction of 2.5 to 10 wt. % has marked effect on wear rate. The volume fraction of reinforcement decreases the wear rate of material. [11]

Serajul Haque et al. in 2014 investigated that the Mechanical and Machining Properties Analysis of Al6061-Cu-Reinforced SiCP Metal Matrix Composite .The process parameters at which best mechanical properties of Al6061, 4% Cu and reinforced 5% SiCp ceramic MMC can be obtained. The addition of 4% Cu in Al6061 is more or less comparable to the composition duralu-min, which are widely used in aerospace applications. SiCp is hard and has linear thermal expansion at high temperature. With reinforcement of SiCp in Al6061-Cu alloy, it can be postulated that hardness of MMC retains at high temperature applications. An analysis of Variance (ANOVA) and linear regression was used for analysis of data with the help of SPSS (Version-17.0). Independent parameters are five levels of pouring rates (1.5 cm/s, 2.0 cm/s, 2.5 cm/s, 3.0 cm/s and 3.5 cm/s), and material type (Al6061 + 4% Cu alloy and Al6061 + 4% Cu, rein-forced 5% SiCp MMC processed using stir casting technique) and dependent parameters are hardness and impact strength material removal rates of workpiece. He used Stir Casting Technique and for Scanning Electron Microscopy (SEM).he was observed that the Reinforcement .of SiCp increases the impact strength, hardness and also material removal rate. Increased material removal rate due to addition of SiC particulates is concluded as better machinability of MMC as compared to base alloy. Increase in poring rate increases the impact strength and haris observed from SEM study that at pouring rate 2.5 cm/s better homogeneity can be obtained. 6) Reason of improved mechanical properties of the composites compare to matrix alloy may be the stir casting technique of production and reinforcement of SiCp. 7) Material removal rate is high in MMC compared to matrix alloy means better machining property is obtained if up to 5% SiC is reinforced in matrix alloy. 8) Pouring rate does not significantly affect the material removal rate for both matrix alloy and MMC dness of material up to a certain limit after that these properties decrease drastically.[12].

Mohamed Zakaulla et al. in 2014 studies of corrosion properties of Al 6061 metal matrix composites rein- forced with varying percentage of uncoated and Cu coated silicon carbide in 3.5 wt% NaCl solution using weight loss method. The processing route used for the composites was stir casting technique. Mass loss and corrosion rate measurements were utilized as criteria for evaluating the corrosion behavior of composites. The surface morphology of composites after the corrosion test is determined by using scanning electron microscopy. In this study, matrix selected was Al6061 which is pro-cured in form of Ingots. The experimental setup for making cast composite consists of mechanical stirrer and a electrical resistance furnace. Copper coated sic particles (containing 30% copper as coating) were added to vortex at approx. rate of 50 g/ min and stirring was done for 10 mines and stirrer was taken out of crucible. He found that Corrosion rate decreases with increasing in duration of exposure to 3.5 wt% NaCl solutions implying that the corrosion resistance of materials tested increases as exposure time is increasing. At early stages, corrosion starts in depth as ob-served at Al/SiC interface which is active sites and later due to excessive polarisation, expands to surface which indicate that corrosion type is pitting. Corrosion rate increases with increasing in wt frac-tion of uncoated and Cu coated SiC. Cu coated 8% SiC recorded a max corrosion rate of 1.937 mpy in 3.5 wt% NaCl solution. It is observed that Electroless Cu coating is not an effective method to improve the corrosion resistance in structural applications despite improving the wettability of SiC. [13].

4. Conclusion

It is concluded that aluminium alloy with reinforcement is clearly better to base alloy. It improves the mechanical properties with their excellent quality of tensile strength, impact strength, wear resistance, hardness and corrosion resistance etc. Fatigue properties of aluminium cast alloy is also presents a better results as compared to other materials but sometimes presence of porosity may cause not so much desirable results. It is also concluded that after adding of reinforcement to the base metal properties like electrical and thermal are also improve compared to base metal.

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