Review on Effect of Reinforcement on Stir Casting Aluminium Metal Matrix Composite.

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Abstract: The potential for extensive application of Aluminium Metal Matrix Composites is very large in Globally, specially in the areas of transportation, energy & electromechanical machinery; the extensive use of composites can lead to large saving in materials & energy and in several instances, reduce environ metal pollution. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcement Like particulate Silicon Carbide (SiC), Graphite (Gr), Molybdenum disulphide (MoS_2), Titanium Carbide (TiC), Alumina fly ash etc. can easily be incorporated in the melt using cheap and widely available Stir Casting method. This paper presents a review on effect of reinforcement on Stir Casting Aluminium Metal Matrix Composites (AlMMC's) containing single and multiple reinforcement. Addition of ceramic particles such Al_2O_3, SiC, MoS_2, TiC, Gr and Fly ash up to certain percentage to Aluminium have shown an increase in mechanical properties.

Keywords: Aluminium Metal Matrix Composites, Aluminium Hybrid Metal Matrix Composites, Reinforcement, Ceramic particles, Stir Casting.

1. INTRODUCTION

Now a day, the development of lightweight Aluminium alloys improves the quality of the material preferred as design material. By mass, aluminium makes up about 8% of the Earth's crust, where it is the third most abundant element (after oxygen and silicon) and also the most abundant metal. A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. Its properties and structural performance are superior to those of the constituents acting independently. Metals and ceramics, as well, can be embedded with particles or fibers, to improve their properties; combination are known as metal matrix composite (MMC). When at least three materials are present, it is called a hybrid composite. Metal Matrix Composites are alloying two or more elements so as to get an alloy material which combines advantages of both reinforcement and metallic matrix. These could be in the form of continuous fibers, short fibers, particles and whiskers utilized in building superior structures and components for various mechanical applications. Reinforcements Aluminium Metal Matrix composite has shown a significant improvement in wear resistance, elastic modulus and tensile strength. Transfer of shear load at the interface of the matrix material and the reinforcement is major reason due to which the resultant alloy exhibits improved mechanical properties of particulate composites.

Aluminium metal matrix composites (Al MMCs) are being considered as a group of new advanced materials for its light weight, high strength to weight ratio, good stiffness to weight ratio, high corrosion resistance, high specific modulus, low co-efficient of thermal expansion and good wear resistance properties. Matrix is aluminium, magnesium, titanium and their alloys. Aluminium metal matrix composites (Al MMC) are the composites in which aluminium is used as the matrix and several reinforced materials are embedded

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into the matrix. John E. Allison and Gerald S. Cole Metal Matrix [17] Composites offer considerable promise to help automotive engineers meet those challenges of current and future demands for recyclable, fuel – efficient, safe and Low- emission vehicles. These materials can be engineered to match the design requirements of automotive power – train or chassis components. Technological and infrastructural barriers tend to limit the implementation of these materials, but it is believed these barriers can be overcome and that metal – matrix composites can be applied in high – volume vehicle production. Improving fuel economy, reducing vehicle emissions, increasing styling options, enhancing performance, and maintaining safety, quality, and profitability are just a few of the challenges addressed daily by the automotive industry.

Many alloying elements have been used to produce Aluminium alloys. General purpose applications usually employ this alloy. Reasons for which are mostly attributed to its good weldability and mechanical properties. Aluminium alloys commonly available are 7075-0; 7075-T6 and 7075-T651 are graded based on the way they are processed. Annealing, solutionised, stress-relieved stretching and artificial aging are some of the main processing technique employed for the same. Mechanical properties such as dislocation generation, strengthening mechanism etc need to be profiled for Aluminium alloys with various proportions of MoS_2/TiC and other reinforcements and researched to look for best alternates available for various applications. Aerospace, defence, automotive industries adopt such composites because of its unique properties such as strength-to-weight, strength-to-cost ratios, high specific strength, wear resistance. Aero, automobile and marine industries are therefore constantly looking for such alternates.

Table- 1: Quick Reference Chart – Choosing an Aluminum Grade **(M. Dinesh et al.)**

Metal	Formability or Workability	Weldability	Machining	Corrosion Resistance	Heat Treating	Strength	Typical Applications
Alloy 1100	Excellent	Excellent	Good	Excellent	No	Low	Metal Spinning
Alloy 2011	Good	Poor	Excellent	Poor	Yes	High	General Machining
Alloy 2024	Good	Poor	Fair	Poor	Yes	High	Aerospace Application
Alloy 3003	Excellent	Excellent	Good	Good	No	Medium	Chemical Equipment
Alloy 5052	Good	Good	Fair	Excellent	No	Medium	Marine Applications
Alloy 6061	Good	Good	Good	Excellent	Yes	Medium	Structural Applications
Alloy 6063	Good	Good	Fair	Good	Yes	Medium	Architectural Applications
Alloy 7075	Poor	Poor	Fair	Average	Yes	High	Aerospace Applications

2. LITERATURE SURVEYS

S. Suresh et al [1] investigated the effect of mechanical stir casted on Al7075 with nano Al_2O_3 has been studied. The hardness, tensile strength and Impact strength results of Al7075 MMNCs have been improved as compared to the Al7075 base alloy. V. Ramakoteswara Rao et al. [3] studied the effect of sliding distance, sliding velocity and wt% of reinforcement on the volumetric wear rate of AA7075 as matrix material & TiC reinforced material. Results show that volumetric wear rate decreases with increasing sliding velocity etc. N. Rajesh Prabha et al. [4] reported the dry sliding performance of the stir casted Al7075 / TiC / MoS_2 hybrid Metal Matrix Composites and optimization using Taguchi method. The parameters selected for this experimental study are applied load, sliding velocity & sliding distance. The experiments were carried out using Taguchi technique with an L27 orthogonal array. Results shows that the increasing wear parameters it also increases the wear. Ms. Kanchan A. More et al. [6] success fully examined the Wear behaviors of hybrid composites of Al7075 alloy reinforced with TiC & MoS_2 hybrid composites prepared by the method of stir casting. Results revealed that reinforcement shows negative influence on weight loss. Weight loss decreases with increasing reinforcement. Hybrid Aluminium Metal Matrix Composites has a series of excellent properties i.e. high hardness, stability and low density. V. Ramakoteswara Rao et al. [7] Aluminium Metal Matrix Composites (AMMCs) reinforced with particulates has marked their importance in many engineering applications because of low wear rate and a significant hardness. Al7075 metal matrix composite materials varying in the particle percentage of TiC reinforcement, were prepared by stir casting procedure and optimized volumetric wear at different parameters such as particle percentage of TiC, sliding speed & sliding distance. S. Devaganesh et al. [8] Al7075 tends to have a vast numbers of applications in fields of automobile, aerospace, mechanical and marine industries due to its high strength to density ratio, high tensile strength, high yield strength and high elongation during the time of failure. In most of the fields mentioned above, Al7075 alloy is either used in the form of metal matrix composite. Devaganesh S. et al. focused on fabrication of Al7075 Metal Matrix Composites (MMCs) with silicon carbide ceramic particles & various others solid Lubricants for application in the development of piston. The composites of the casted specimen is 90 wt% Al7075 alloy as well as 5% of SiC, which has to be kept as constant and varying the type of the solid lubricants; graphite, hexagonal boron nitride (hBN), and molybdenum disulfide (MoS_2) with 5 wt%. V. Ramakoteswara Rao et el. [9] Al 7XXX series alloy also called aluminium – Zinc alloy due to maximum Zinc quantity ranging between 5.1 – 6.1 percent & chemical composition shown in Table-1. Al7075 has wide verities of applications due to this it need further reinforcement. The aluminium alloy is used as matrix material & builds with several properties by adding desirable single and multiple reinforcement particulates like SiC, Al_2O_3, Gr, TiO_2, B_4C, AlN, fly ash etc. as Composites which shows higher strength than the base alloy material. G.B. Veeresh Kumar et al. [13] the composites are prepared using the liquid metallurgy technique, in which 2-6 wt. %'age of particulates was dispersed in the base matrix in steps of 2. The obtained cast composites of Al6061-SiC and Al7075–Al_2O_3 and the castings of the base alloys were carefully machined to prepare the test specimens for density, hardness, mechanical, tribological tests and as well as for microstructural studies as per ASTM standards. The SiC and Al_2O_3 resulted in improving the increased %'age of these reinforcements contributed in increased hardness and density of the composites. The microphotographs of the composites studied revealed the uniform distribution of the particles in the matrix system. D. Srinivasan et al. [14] Studied the over view of Al7075 Metal Matrix Composites such as metallographic phenomenon of AMCs Like agglomeration, bonding strength, distribution of particulates in the matrix and fabrication techniques of Aluminium MMCs [14]. Sneha H. Dhoria et al. [15] successfully reviewed the Literature available on various Aluminium based hybrid metal matrix composites used in present day applications. The effect of different hybrid reinforcements on AMC's in terms of their mechanical & tribological properties like tensile strength, strain, hardness, wear & fatigue was discussed [15]. Mohammed Imran et al. [16] investigated of mechanical properties, tribological properties & corrosion behavior of Al7075 MMCs by the addition of desirable reinforcements. John E. Allison and Gerald S. Cole Metal Matrix [17] Composites offer considerable promise to help automotive engineers meet those challenges of current and future demands for recyclable, fuel – efficient, safe and Low- emission vehicles. These materials can be engineered to match the design requirements of automotive power – train or chassis components. Technological and infrastructural barriers tend to limit the implementation of these materials, but it is believed these barriers can be overcome and that metal – matrix composites can be applied in high – volume vehicle production. Improving fuel economy, reducing vehicle emissions, increasing styling options, enhancing performance, and maintaining safety, quality, and profitability are just a few of the challenges addressed daily by the automotive industry. J. Hashim et al. [18] Mechanical stirring is necessary to help to promote wettability. Isothermal stirring in semi- solid condition at a temperature in the solidification range (590^0C), then re- stirring in a fully liquid condition before pouring, also gives zero wettability. Using magnesium enhances wettability, however, in- creasing the content above 1 wt. % Mg increases the viscosity of the slurry to the detriment of particles distribution.

3. MANUFACTURING PROCESS

Table- 2: Study of different manufacturing process **(Hashim et al., 1999)**

Method	Range of shape and size	Metal yield	Range of volume fraction	Damage to reinforcement	Cost
Stir Casting	Wide range of shapes, larger size up to 500kg	High	Up to 0.3	No damage	Least expensive
Powder Metallurgy	Wide range restricted by size	High	_	Reinforcement fracture	Expensive
Squeeze Casting	Limited by perform shape up to 2cm height	Low	Up to 0.45	Severe damage	Moderately expensive
Spray Casting	Limited shape, large size	Medium	0.3 to 0.7	_	Expensive

Mechanical Stirring	Not limited by size	Medium	0.4 to 0.7	Little damage	Moderate
Electromagnetic Stirring	Not limited by size	High	0.5 to 0.8	No damage	Moderately expensive

Stir Casting Process

The many methods of production stir casting route is simple and less expensive and is preferred method for mass production. According to the type of reinforcement, the fabrication techniques can vary considerably. From among the contributions of various researchers some of the techniques for manufacturing these composites are stir casting powder metallurgy, spray atomization and co deposition, plasma spraying and squeeze casting. These processes are most important liquid metallurgy techniques have been explored. This involves incorporation of ceramic particles into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The most popular and commercially most employed method used technique is known as vortex technique or stir casting technique. The stir technique involves the introduction of pre treated ceramic particles into the stir of molten alloy created by the rotating impeller. There are many parameters in this process, which affect the final microstructure and mechanical properties of the composites.

Stir casting is generally accepted as a promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production with cost advantage. The major problem of this process is to obtain sufficient wetting of particle by liquid metal and to get a homogenous dispersion of the particulates. Stir casting is a liquid state method for the fabrication of composite materials, in which a dispersed phase is mixed with a molten matrix metal particularly.

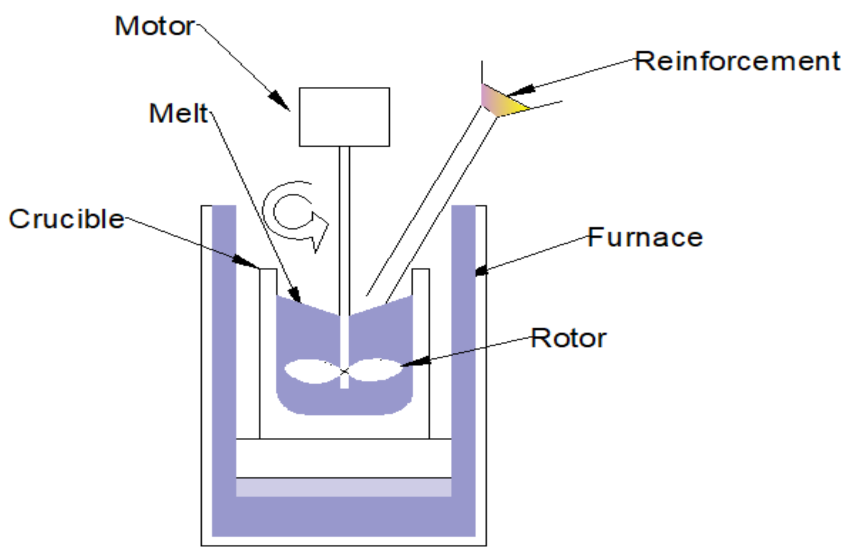

Fig. 1: Stir Casting

4. MECHANICAL PROPERTIES OF ALUMINIUM METAL MATRIX COMPOSITES (Al MMC's)

The aluminium metal matrix composites have various effects on the mechanical properties that impart many modern-day applications. Investigation on mechanical properties tends to make the study of composites in depth. The various mechanical properties that are considered in the present study are as follows:

4.1 Density:-

Density is defined as its mass per unit volume. Density is a measurement that compares the amount of matter and object has to its volume. An object with huge matter in a fix volume has high density. The SI unit of density is kilogram per cubic meter (kg/m^3). S.Suresh et al. [1] it is clear that the density values reduced with increasing weight % of Nano Al_2O_3 particles when compared to the base metal (Al 7075). G.B.Veeresh Kumar et al. [13] The densities of composites are higher than that of their base matrix, further the density increases with increased percentage of reinforcement content in the composites. It can be concluded that Al7075-Al_2O_3 composites exhibits higher density than that of the Al6061-SiC and can reasoned for the higher density values of Al_2O_3.

4.2 Hardness:-

Hardness is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion. Some metal are harder than other (e.g. plastics, wood). Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelectricity, and viscosity. Common examples of hard matter are ceramics, concrete, certain metals, and super hard materials, which can be contrasted with soft matter. Vickers hardness test is carried out in the hybrid composite material after the casting has been done. Micro hardness tests are used to provide necessary data when measuring individual microstructures within a larger matrix or when determining the hardness gradient of a specimen along its cross section. The Vickers hardness test uses a square-based pyramid diamond indenter with an angle of 136º between the opposite faces at the vertex, which is pressed into the surface of sample using a prescribed force F. Time for the initial application of the force is 2sec to 8sec and is maintained for 10sec to 15sec. Diagonal lengths of the indentation are measured and the arithmetic mean d is calculated after the force has been removed.

S.Suresh et al. [1] a contrast in between hardness values of as cast as well as heat treated with aluminium oxide enhanced aluminium matrix composites could additionally be observed. It is seen that heat treatment increased the hardness values. Veeravalli Ramakoteswara Rao et al. [2] The Hadness Maximum the 8 wt. % of TiC reinforcement at both cast and heattreated conditions. S. Devaganesh et al. [8] When compared to Al7075, Al7075 + 5%SiC + 5%Gr and Al7075 + 5%SiC + 5%MoS2 alloys have improved in Vickers hardness number by 44.3% and 10.7% respectively whileAl7075 + 5%SiC + 5%hBN has decreased by 1.6%. Drastic changes in the hardness value of the composite materials are due to the existence of reinforcements. V. Ramakoteswara Rao et al. [9] it can be observed that hardness shows increasing trend with increasing percentage of TiC particulates. However, declining of hardness was observed for C5 composite due to agglomeration and casting defect. This hardness increase was observed from 181 VHN for matrix metal to 202 VHN at 8 wt% TiC reinforced composite (C4) at T6 condition. This could be due to the presence of TiC particulates which are hard in nature. M.Dinesh et al. [10] finally composite contain (Al-97%Cr-4%Zn-1%) fabricated composite showed improved Hardness properties in comparison with other specimens. S. Suresh et al. [12] in the present work, research on the mechanical and wear properties of Al 7075 / Al_2O_3 / SiC was done. The Al 7075 alloy reinforced with 1, 2, 3 and 4 wt. % of nano - (Al_2O_3 + SiC) composites has efficiently manufactured by stir casting process. Alloying of Al matrix with 1 wt. % Mg and its segregation at the interfaces has been found to be effective in restricting the formation of the Al_4C_3 at the interfaces during casting. Oxidation of reinforcement particles has prevented / restricted the chemical reaction at interfaces. The hardness values increase by increasing the weight percentage of nano- Al_2O_3 and nano - SiC reinforcement. G.B.Veeresh Kumar et al. [13] the hardness of the composite is greater than that of its cast matrix alloy. The composites containing higher filler content exhibits higher hardness. The hardness of the Al7075 - Al_2O_3 composite are higher than that of the composite of Al6061-SiC and is to the fact that the matrix Al7075 and Al_2O_3 possess higher hardness.

4.3 Tensile:-

When the reinforcements are mixed with Al-MMCs the resulting material exhibits significant increase in its elastic modulus besides hardness and wear resistance. Al MMC reinforced particles have improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance. The specimen with known dimensions, like length and cross-sectional area is subjected to tensile testing. Weight is applied to one end that is gripped to the testing machine while the other end is fixed. Gradually stress in the form of weight is increased while at the same time measuring the change in length (strain) of the sample. The strain value increases proportionally as the stress value increases until a maximum limit. Strain drops beyond maximum limit for any further stress increase.

S. Suresh et al. [1] The clear that an increase in the yield and ultimate strength of heat-treated samples over un-heat treated samples and also with the 4 wt.% of Al_2O_3 had increased yield and ultimate strength over samples with 0 wt.% of Al 7075. Veeravalli Ramakoteswara Rao et al. [2] The tensile test results for as cast condition generally lower than the heat treated condition values of the same compositions due to the good hardness at heat treated condition. P. Saritha et al. [5] Addition of Silicon Carbide particles further

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more than 5% did not improve the tensile strength, the maximum tensile strength is seen for (5% SiC & 3% MoS_2) i.e., 161.79 N/mm^2 and the minimum is seen which is pure 7075 alloy i.e., 126.46 N/mm^2. S. Devaganesh et al. [8] The tensile strength of the Al7075 + 5%SiC + 5%Gr has increased by 277.6%, 24.4%, and 80.0% when compared toAl7075, Al7075 + 5%SiC + 5%hBN and Al7075 + 5%SiC + 5%MoS2 respectively, this is because the fortification of graphite particles in the alloy comprehensively ameliorates the composite resistance. M.Dinesh et al. [10] Composite contain (Al-97%Cr-4%Zn-1%) fabricated composite showed improved properties such tensile in comparison with other specimens. S. Suresh et al. [12] in the present work on the mechanical and wear properties of Al 7075 / Al_2O_3 / SiC was done. The Al 7075 alloy reinforced with 1, 2, 3, and 4 wt. % of nano - (Al_2O_3 + SiC) composites has efficiently manufactured by stir casting process. Alloying of Al matrix with 1 wt. % Mg and its segregation at the interfaces has been found to be effective in restricting the formation of the Al_4C_3 at the interfaces during casting. Oxidation of reinforcement particles has prevented / restricted the chemical reaction at interfaces. The tensile strength (UTS) values increase by increasing the weight percentage of nano- Al_2O_3 and nano - SiC reinforcement. G.B.Veeresh Kumar et al. [13] It can be observed that the tensile strength of the composites are higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite. Also from the figure it can be observed that the tensile strength of the Al7075 - Al_2O_3 composites is higher than that of the composites of Al6061 - SiC.

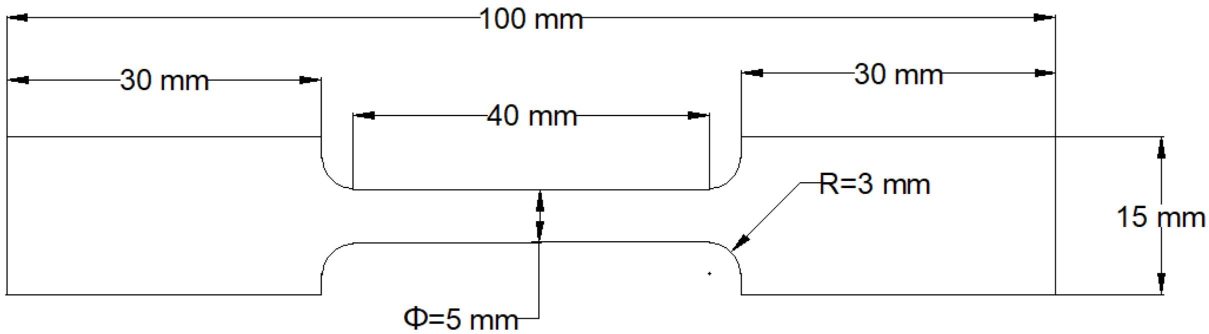

Fig. 2: Dimensions of tensile test specimen

4.4 Wear Behavior:-

Wear is defined as a damaging, gradual removal or deformation surface damage of one or all solid surfaces in contact subject to relative motion. Wear might have different patterns corresponding to various wear mechanisms. A surface can be subject to more than one wear mechanism simultaneously. The process of wear can change continuously in time or with changes in operational conditions. Causes of wear can be mechanical (e.g. erosion) or chemical (e.g. corrosion). The study of wear and related processes is referred to as tribology. Wear is usually accelerated by the frictional heating by means of chemical and mechanical interactions.

Veeravalli Ramakoteswara Rao et al. [2] The wear rate of AA7075/8 wt.% TiC composite at T6condi-tion was found to be optimal wear rate compare to the cast conditions and AA7075 matrix material. S. Devaganesh et al. [8] The specific wear rate of Al7075 + 5%SiC + 5%hBN decreased by 92.9%, 36.8% and 88.6% as compared toAl7075, Al7075 + 5%SiC + 5%Gr and Al7075 + 5%SiC + 5%MoS2 respectively. The reinforcement of hBN gives higher wear characteristics as compared to other reinforcements. V. Ramakoteswara Rao et al. [9] it is clearly noted that the wear rate decreases with increasing TiC weight fraction and sliding distance. It should be observed that the effect of sliding distance and wt % of reinforcement over a wear rate is same nature at different conditions i.e., inversely proportional. The wear rate of the composites decreased with increasing the weight percentage of Titanium carbide (TiC) particulates than the base alloy. S. Dhanalakshmi et al. [11] Taguchi's method is used to find the optimum conditions to achieve better wear resistance under dry sliding condition for the hybrid Al7075 - Al_2O_3 –B_4C composites produced through stir casting method. The wear resistance is increases with increasing Al_2O_3 weight percentage in the composite. ANOVA results show that load has the highest influence followed by sliding speed and distance, both on wear rate and coefficient of friction. S. Suresh et al. [12] The Al 7075 alloy reinforced with 1, 2, 3 and 4 wt. % of nano - (Al_2O_3 + SiC) composites has efficiently manufactured by stir casting process. Alloying of Al matrix with 1 wt. % Mg wear properties of Al 7075 / Al_2O_3 / SiC was done. Hybrid metal matrix nanocomposites exhibit a significant decrease in friction coefficient and wear rates with an increase in the wt. % of reinforcement particles. G.B.Veeresh Kumar et al. [13] the wear resistance of the composites are higher, further the SiC contributed significantly in improving the wear resistance of Al6061-SiC composites.

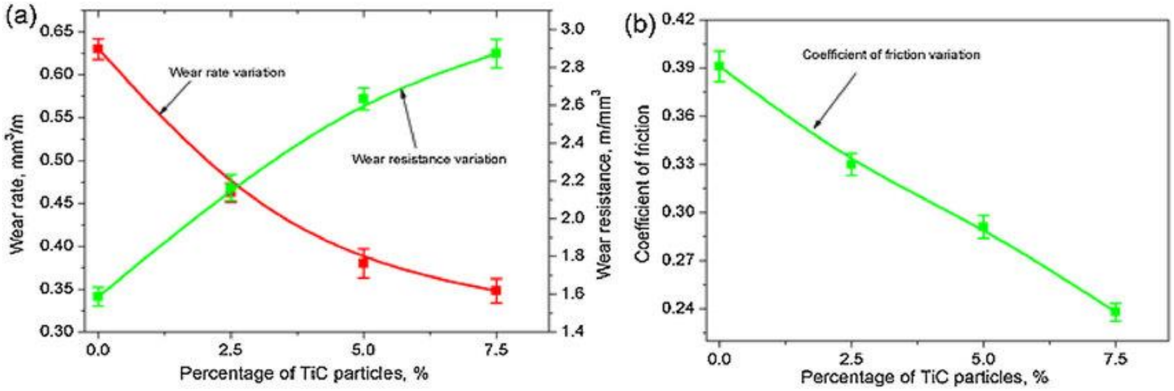

Fig. 3: Wear

4.5 Microstructure:-

Optical Metallurgical microscope is used to study the distribution of silicon carbide inside the aluminium matrix. Average size of the aluminium particles visualized is 100 µm. It is observed that the distribution of ceramic particles inside the matrix of aluminium is uniform over the matrix, which is maintained by constant stirring the melt and the uniformity is verified in the microstructure. It is to be noted that the ceramic particles appear black against a bright background. Further, the distribution of aluminium particles is more even.

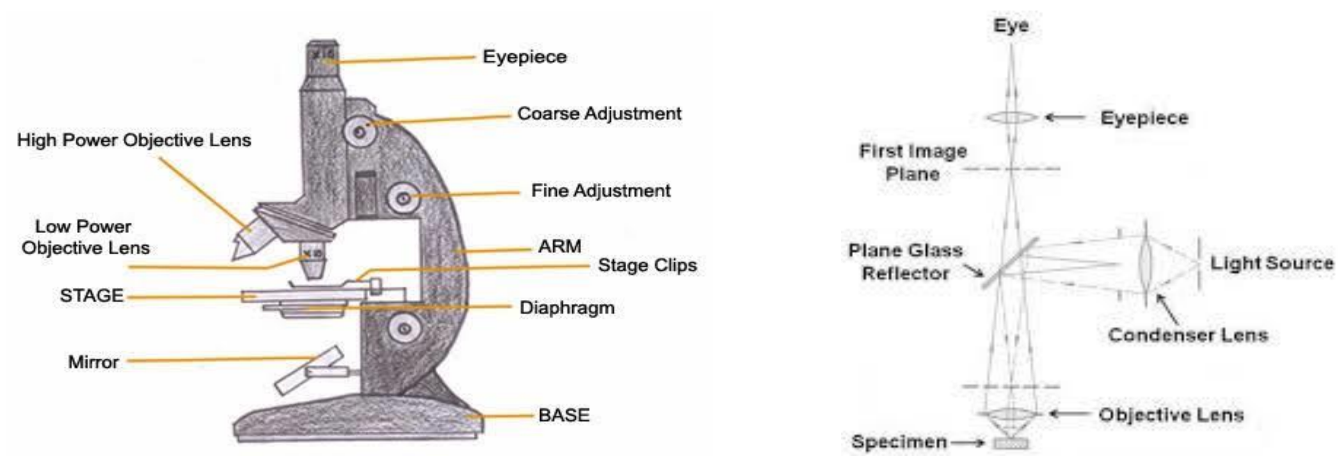

Fig. 4: Microscope Equipments

In order to make the crystal structure visible, the sample surface must be initially ground even and then polished. After completion of the last polishing step, first predictions about the purity of the material can be ascertained through the different reflexions. In order to make crystal structure visible for being contrasted .If the crystalline structure contrasts correctly in this manner, then the sample can be evaluated if and when a hardness test is to be performed (micro and universal hardness tester) then all common –phase test procedure. S. Suresh et al. [12] in the present work, research on the SEM examination of Al alloy and its nanocomposites produced under optimum conditions mentioned above show that distribution of reinforcement particles is homogeneous; reactions on the SiCp / matrix interface are not observed. The mechanical behavior of the composites increases with increasing wt. % of nano (Al_2O_3 + SiC) when compared with the unreinforced alloy. XRD analysis clearly shows the presence of elemental composition and also the presence of Al, Al_2O_3, and SiC in the composite.

5. CONCLUSION

The above review for the effect of reinforcement on stir cast Aluminium MMCs leads to the following conclusions.

i. Al MMCs with tailored properties have the potential of becoming one of the fastest growing families of new material, which can have a large impact on world.
ii. Stir casting method can be successfully used to manufacture metal matrix composite with desired properties.
iii. Reinforcing Aluminium & its alloy with ceramics particles has shown an appreciable increase in its mechanical properties.
iv. Hybrid ceramic reinforcement has increased the mechanical properties.
v. A meager literature has reported about modified stir casting methods for improving the distribution of the reinforcement in the matrix.

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