Effect of Process Parameters in Fabrication of 10%SiC Reinforced Al 6061 MMC using Stir Casting Method

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Abstract

Metal matrix composites materials have wide range of applications due to high specific strength as well as good corrosion resistance. Metal Matrix Composites are the class of composite materials finding vast applications in automotive, aircraft, defence, sports and appliance industries. Such materials are fabricated by using different methods. Though these processes are not considered economical in the manufacturing of large structural components. Among all these methods, Stir casting appears to be very attractive as it is less costly and offers a wide range of material and processing condition options. In Stir casting, process parameters like stirring rate, stirring temperature, pouring temperature etc., are to be maintained for achieving improved behaviour and performance in the MMCs. In the present study, 10%SiC Reinforced Al 6061 metal matrix composites were fabricated by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and some resultant mechanical properties.

***Keywords*:** Metal matrix composites (MMC), Aluminium matrix composite (AMC), Reinforcement, particle distribution, Stir casting.

1. Introduction

Now-a-days, our life becomes comfortable with the development of various technologies due to accessibility of suitable materials. Composite is a combinations of materials differing in composition or form on a macro scale. Composite materials consist of synthetic fibres embedded within a matrix, a material that dispersed and is throughout bounded with the fibres. The most important benefits of composite over the conventional material are light weight, corrosion and fatigue resistance, high stiffness and strength. [1] There are three main types of composite matrix materials: Ceramic matrix composites (CMCs), Metal matrix composites (MMCs) and Polymer matrix composites (PMCs). All engineering materials can be used as matrix for the production of MMCs. Aluminium, magnesium, titanium and their alloys are the most commonly used matrix materials in the production of MMCs due to their lightness, high temperature resistance and ductility. Materials like SiC, SiO_2, Al_2O_3 , B_4C and MgO are generally preferred as reinforcement elements. These can be used as long fibers, short whiskers or particles in either an irregular or spherical shape. The properties of the resulting composites are generally controlled by three critical components: Matrix, Reinforcement and Interface. AlSiCp composite material used on inside edge of body panel of automobiles, on the ceiling of automobiles for weight ratio management. Table.1 shows the composition of MMC with metal matrix & reinforcement material.

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement materials in the matrix alloy must be uniform, and the wettability of bonding between these two substances should be optimized. The chemical reaction between reinforcement materials and the matrix alloy and porosity must be avoided or minimised. A sufficient bond is achieved only when good wetting of the reinforcement by the matrix is obtained, and this is dependent on the surface properties of the two phases. It is believed that a strong interface permits transfer and distribution of load from the matrix to the reinforcement, resulting in an increase in elastic modulus and strength. Fracture in discontinuously reinforced composites can result mainly from de-bonding of particles from the matrix [10].

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Table 1. Composition of MMC with Metal Matrix & Reinforcement Material.

Name of the MMC	Matrix Metal	Reinforcement		
		1	2	3
Al/SiC/Al_2O_3	Al	SiC	Al_2O_3	
Al/SiC/TiB_2	Al	SiC	TiB_2	
Al6061/TiB_2/12p	Al6061	TiB_2	12p	
Al/SiC/B_4C	Al	SiC	B_4C	
Al6063/SiC/ Al_2O_3/Gr	Al6063	SiC	Al_2O_3	Gr
Al/B_4C	Al	B_4C		
Al7075- Al_2O_3	Al7075	Al_2O_3		
ZC63/ Mg Alloy/ Fly ash	ZC63Mg	Fly ash		
Mg/Y_2O_3	Mg	Y_2O_3		
Mg/Al/Si	Mg/Al	Si		
Mg/1.3CNT	Mg	1.3CNT		
Mg-Al-Sn-GNPs	Mg/Al	Sn	GNPs	
AA2219-TiB_2/ZrB_2	AA2219	TiB_2	ZrB_2	
Al217+9% B_4C	Al217	B_4C		
Al2017+9%B4C+3%Gr powder	Al217	B_4C	Gr	

After the development of mixing techniques, by which ceramic fibres or particles were dispersed in matrix metals, the research on evaluation of those composites became very active and many papers about it have been published. [11]. Stir casting is the cheapest and easiest and the applications like automotive and aeronautics involves manufacturing and utilization of large number of components, so the price should be low and the process should be easy and simple. Lot of researches is going on this area by varying different parameters. Stir casting of metal matrix composites suffers from several limitations like uneven distribution, low wettability and cluster formation. Designing and trying out inventive impeller geometry can overcome all these limitations. Hence, researches focused on designing, fabricating and testing different stirrers and feeders and utilizing them in stir casting for the manufacturing of different metal matrix composite material [12]. The most important challenge during fabrication of metal matrix composites (MMCs) by liquid phase processes are uniform mixing of reinforcement in the matrix without sinking, floats and wettability of ceramic particles in the base metal with less porosity and higher density. To overcome these challenges, adding nano particles by stirring with squeeze casting procedure was adopted. [15]

1.1. Objectives for MMC Development

The objective of metal matrix composite material development is to combine the desirable properties of metals and ceramics. The reinforcement takes the form of particles, whiskers, short fibers, or continuous fibers in the MMCs. The metal reinforcement have different objectives. The reinforcement of light metals opens up the possibility of use of these materials in areas where weight reduction is the first priority. [2] The development objectives for light metal composite materials are:

1. Increase in creep resistance at higher temperatures compared to that of conventional alloys,
2. Increase in yield strength and tensile strength at room temperature and above while maintaining the minimum ductility or rather toughness,
3. Increase in fatigue strength at high temperatures,
4. Improvement of thermal shock resistance,
5. Improvement of corrosion resistance,
6. Increase in Young's modulus,
7. Reduce density,

8. Controlled thermal expansion coefficient.

1.2. Advantages & Applications of Composites

Composite materials have different properties like light weight, high strength, corrosion resistance, high-impact strength, design flexibility and dimensional stability. It finds huge application in aerospace, automotive, structural and marine industries include performance, economic and environmental benefits. [3] Light weight metal-matrix composites have been attracting growing interest and introduced into the most important applications in the automotive industry.

Aluminium matrix composite (AMC) is an attractive class of composite materials which possesses the material requirements for structural applications in the automotive industry. The major requirement of AMC in the auto industry is as a result of its mass reduction; improve wear resistance and material properties particularly high strength and stiffness. Aluminium based MMC has attracted by researchers due to its low density, high thermal conductivity, low melting point and the ability to be reinforced by a wide variety of reinforcement phases such as SiC, Al_2O_3, TiC, B_4C and fly ash. [23]

2. Literature Review

Aluminium A356 alloy with different weight fractions of (0, 5, 7.5, 10 and 12.5%) RHA and Fly ash reinforced hybrid composites were successfully fabricated by using double stir casting technique. [13] Mono and hybrid composites were successfully prepared with B_4C and Gr flakes/ Powder reinforcements respectively using stir casting method. [14] Among all these reinforcement phase, silicon carbide (SiC) is an ideal candidate because of its significant ability to enhance the strength and stiffness, modulus, thermal stability, and abrasive wear resistance of the aluminium matrix. Stir casting methods when used to make the A356/Al_2O_3 micro and nano composites [15] revealed that the nano composites exhibited better properties in terms of compressive strength, hardness with reduced porosity. It was concluded that a 700 rpm stirring speed with 15 min stirring time could produce a composite sample with the incorporation of most of the added particles distributed almost uniformly throughout the microstructure. [16] Aluminium-silicon carbide is a metal matrix composites material consisting of silicon carbide particles dispersed in a matrix of aluminum alloy. It combines the benefits of high thermal conductivity of metal and low coefficient of thermal expansion of ceramic. With its composite features, Al-SiC is an advanced packaging material for high technology thermal management. Al-SiC is compatible with a wide range of metallic and ceramic substrate and plating materials used in microelectronic packaging for aerospace, automotive, microwave applications. Al-SiC allows for a new packaging technology that can replace traditional W-Cu, Mo, BeO, Kovar, Mo-Cu, AlN, AlSi, Al_2O_3.

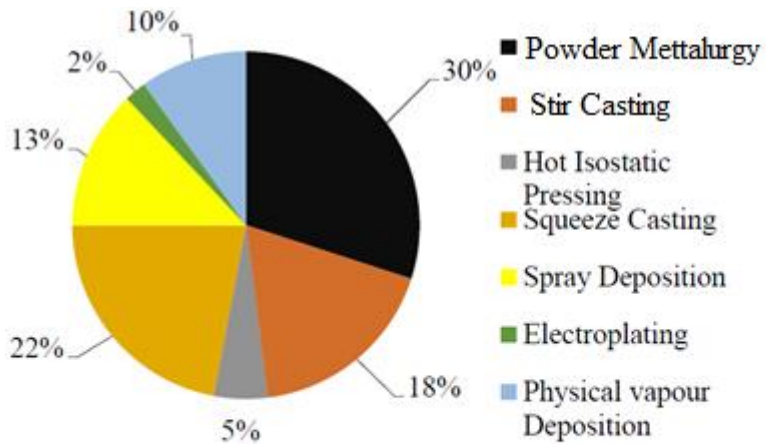

Fig.1. Researches on fabrication routes of MMCs in past decades. [19] [20]

2.1. Fabrication Methods

There are different fabrication methods available in manufacturing of the MMC materials. Fabrication methods can be divided into three types. These are solid phase processes, liquid phase process and semi-solid fabrication process. Solid state processes are generally used to obtain the best mechanical properties in MMCs, particularly in discontinuous MMCs. According to the type of reinforcement, the fabrication techniques can vary considerably. The processes can be classified into five categories: (1) liquid-phase processes, (2) solid-liquid processes, (3) deposition techniques and (4) in situ processes. (5) two- phase (solid-liquid) processes.

Liquid phase fabrication of metal matrix composite 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 methods of liquid state fabrication of Metal Matrix Composites: Stir casting, Infiltration like gas pressure infiltration, Squeeze casting infiltration or Pressure die infiltration.

Stir casting method has a good potential in all-purpose applications as it is a low cost MMCs production method. To obtain a successful reinforcement process in the production of MMCs, the most important and effective criterion is the selection of the appropriate method and material. In order to provide good wettability between matrix and reinforcement particles, stir casting is the most common method used in the manufacturing field.

2.2. Stir Casting

Stir casting of metal matrix composites was found in 1968, when S. Ray introduced alumina particles into aluminium melt by stirring molten aluminum alloys containing the ceramic powders. It 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 as shown in Fig. 1. There are different materials required for stir casting setup: Refractory bricks, crucible, blower, stirrer and charcoal. The stir casting methodology is relatively simple and low cost. It can be prepared by fairly conventional processing equipments by the use of stirring mechanism. [4] A refractory brick is a block of refractory ceramic material used in lining furnaces built to withstand high temperature and have low thermal conductivity. Crucible is the container in which the metal is melted and then poured into a mould to perform casting. The material of the mould should be a very good conductor of heat so that heat loss should be less. There are several materials available for this purpose like silicon-carbide, cast steel and graphite. The blower motor blows out high volume air for proper combustion of the fuel. By controlling the blower speed, the temperature in the furnace can be modified. A stirrer is required which can withstand the high temperature and doesn’t affect the purity of the composite. Charcoal is a lightweight, black residue, consisting of carbon and any remaining ash, obtained by removing water and other volatile.

The liquid composite material is then cast by conventional casting methods and processed by conventional metal forming methods. [5] It has different benefits like simplicity, flexibility and applicability to large quantity production. It is also attractive because it allows a conventional metal processing route to be used and hence minimizes the final cost of the product. The cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement.

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The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added. An interesting recent development in stir casting is a two-step mixing process. In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum metal matrix composite. Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical. For that reason, stir casting is currently the most popular commercial method of producing aluminum based composites.

Major researches have been found on study of quantitatively measures with the actual SiC concentration in Al. The objective of the study is the influence of stir casting process parameters such as processing temperature and holding time on the uniform distribution of particles and resulting mechanical properties.

2.3. Factors considered in preparation of metal matrix composites by stir casting method:

To achieve uniform distribution of the reinforcement material

In the stir casting process it is important that the reinforcement particles should be properly distributed in the molten matrix phase during casting. During this phase sometimes problem arises due to density difference between the reinforcement particles and the matrix alloy melt. It can be avoided by vortex method in stir casting process. In this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry is cast.

To achieve wettability between the two main substances

Wettability can be defined as the ability of a liquid to spread on a solid surface. Successful incorporation of solid ceramic particles into casting requires that the melt should wet the solid ceramic phase.

To minimize porosity in the cast metal matrix composite

In general, porosity arises from three causes: (a) gas entrapment during mixing, (b) hydrogen evolution, and (c) shrinkage during solidification. The process parameters of holding times, stirring speed, and the size and position of the impeller will influence the development of porosity, chemical reactions between the reinforcement material and the matrix alloy.

3. Selection of mixing technique

The method selected for incorporating particles and their mixing with the molten matrix play an important role in distributing the reinforcements. Although several techniques for introducing and mixing particles in the melt is known, a majority of those processes are found to be ineffective in dispersing nanometric particles, i.e. gas injection of particles introduces huge amount of gas into the melt without any significant incorporation of particles in the melt. Mechanical stirring often used for mixing, introduces floating impurities and oxide layers in the melt and excessive stirring can increase the gas content in the melt which increases porosity in the cast sample. Stirring speed and time, melt temperature, prevailing atmosphere over the melt, amount and nature of the particles to be introduced into the matrix are important factors which is required to be monitored and controlled precisely for effective incorporation of nanometric particles in the melt. [6]

3.1. Process Parameters

This liquid metallurgy technique is the most economical among all the available methods for metal matrix composite production, and allows very large sized components to be fabricated. Also the cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including the difficulty of achieving a uniform distribution of the reinforcement material; wettability between the two main substances; Porosity in the cast metal matrix composites; and Chemical reactions between the reinforcement material and the matrix alloy. Following parameters are taken into consideration during MMC fabrication by using stir casting method. It has been observed that melting and pouring conditions have directly or indirectly effect on mechanical properties of cast materials as hardness, percentage elongation, percentage reduction in diameter, toughness and so on. [7]

Stirrer Design: It is the important parameter in stir casting required for vortex formation. It contains blade in which blade angle and number of blades decides the flow pattern of the liquid metal. The stirrer is immersed till two third depth of molten metal. It is required for uniform distribution of reinforcement in liquid metal, perfect bonding as well as to avoid clustering.

Stirrer Speed: Stirring speed is an important parameter to promote binding between matrix and reinforcement i.e. wettability. The flow pattern of the molten metal is directly controlled by the stirring speed. Stirring speed decides vortex formation which is responsible for dispersion of particulates in liquid metal. [8]

Fig. 2 shows the bottom pouring type stir casting furnace.

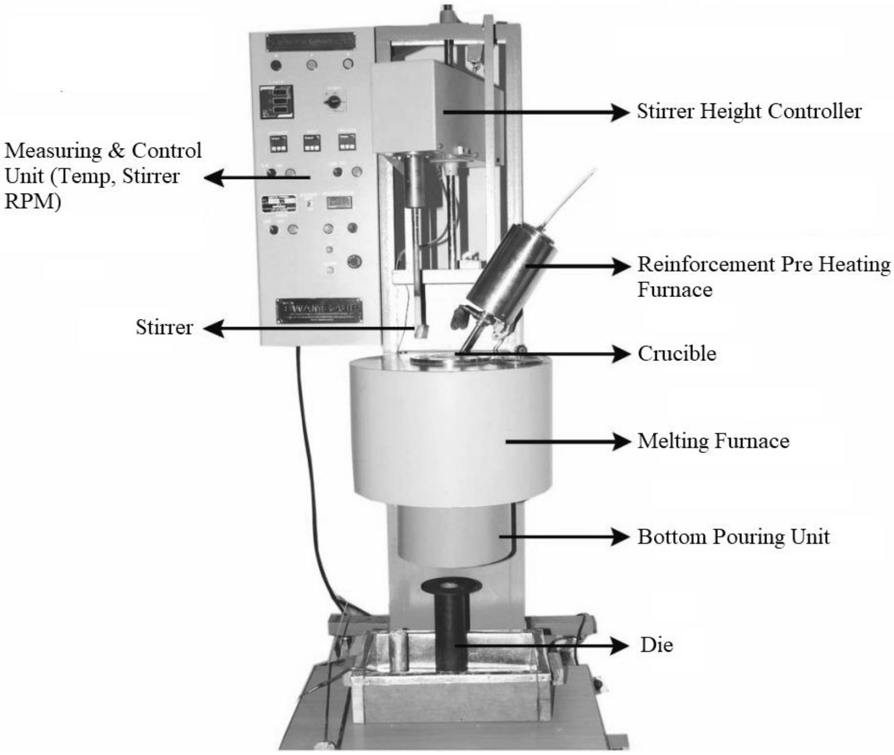

Fig. 2. Bottom Pouring Type Stir Casting Furnace.

Stirring Temperature: The viscosity of matrix material is mainly affected by the processing temperature. The viscosity of liquid is decreased by increasing processing temperature with increasing holding time for stirring which also promote binding between matrix and reinforcement. Good wettability is obtained by keeping temperature about 800°C.

Stirring Time: Stirring promotes uniform distribution of reinforcement partials and interface bond between matrix and reinforcement. Hence, stirring time plays an important role in stir casting. Less stirring leads to non-uniform distribution of particles and excess stirring forms clustering of particles at some places. [9]

Reinforcement feed rate: Non-uniform feed rate promotes clustering of particles at some places which causes the porosity defect and inclusion defect, so the feed rate of powder particles must be uniform to have a good quality of casting.

Pouring of melt: Pouring rate and pouring temperature contributes significantly in casting quality. Pouring rate of slurry must be uniform to avoid entrapping of gases. The distance between mould and crucible also plays an important role in quality of casting.

Pouring temperature: A major role is played by the pouring temperature on the mode of solidification and determines relation partly to the required structure type. Low temperature is associated with maximum grain refinement and equiaxed structure while higher temperature promotes columnar growth in many alloys. However, the range is limited in practical scenarios. To ensure satisfactory metal flow and freedom from collapse whilst avoiding coarse structures, the pouring temperature must be sufficiently high.

Mould temperature: Its principal signification lies in the degree of expansion of the die with preheating. The risk of tearing in casting is diminished by expansion. The mould temperature should neither be too low nor be too high, in non-ferrous casting. The mould should be at least 25 mm thick with the thickness increasing with size and weight of casting. The stir casting parameters which influence the microstructure and mechanical properties of AMCs are shown in Fig. 3.

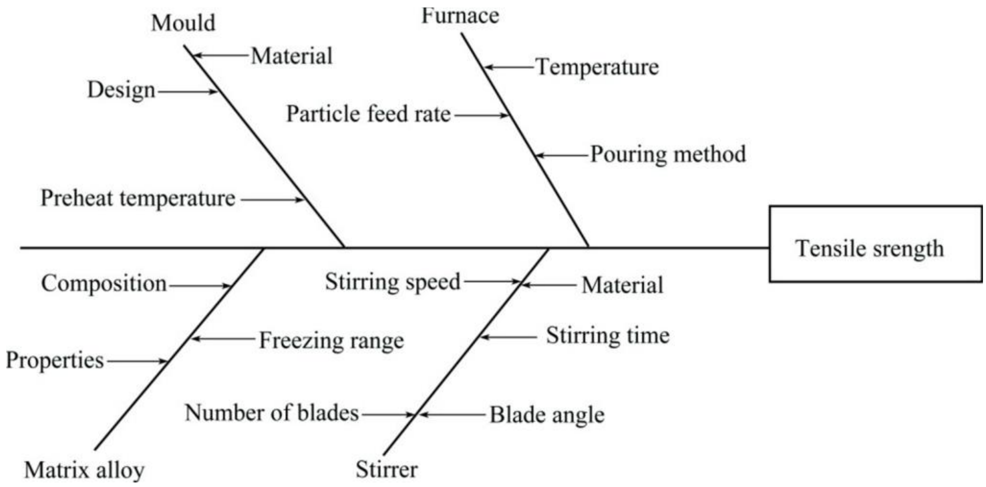

Fig. 3. Stir casting parameters influencing tensile strength of AMCs

3.2. Experimental procedure

The objective for the different mechanical properties and microstructure is to improve the quality of the composite material.

3.2.1 Selection of materials

Preliminary materials utilized for creating AlSiCp alloy composites incorporate SiC particulate matter and Al rod. SiC particulate matter has a normal molecule size of 10 µm and an immaculateness of 94.67 %. The Al (Al6061-T6) rod utilized as a part of this experiment. The chemical composition of Al6061 and SiCp is mentioned in Table 1 & 2 respectively.

Table 2. Chemical Composition of Al6061.

Elements	Mg	Cr	Si	Ti	Fe	Zn	Mn	Cu	Al
Wt %	0.07	0.08	1.08	0.01	0.25	0.01	0.018	0.015	Balance

Table 3. Chemical Composition of SiCp.

Elements	SiC	Fe	SiO_2	Si	C	Al	Ca	Mg
Wt %	96	0.2	0.8	0.5	0.6	0.2	0.65	1.05

3.2.2 Work-Piece Design

The Al6061 matrix composite reinforced with 10 wt% SiC was fabricated by stir casting process. Fig. 2 demonstrates the stir casting setup. The Al6061 composite was liquefied in a graphite crucible and it was placed inside a top loaded resistance furnace at different temperature level (700°C, 750°C, 800°C, 850°C, 900°C). Hardness of the Al-SiC composites increased with increasing wt.% of SiC particles, it is due to the presence of well bonded SiC particles in Aluminium matrix that are hard in nature which causes the movement of dislocations to hinder resulting in increased hardness of composite [22]. Since the SiC particulates are hard in nature thereby resulting in resistance to the applied load causing pinning effect or dislocations pileup and ultimately enhanced hardness. So, the amount of SiC was kept 10% to fabricate the Al6061 metal matrix composite. The four blade Stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material. Four blades stirrer setup is shown in Fig. 4.

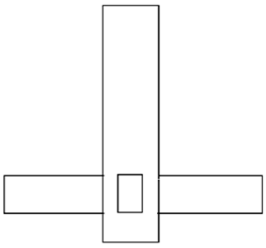

Fig. 4. Four blades Stirrer.

The axial and radial flows are provided to avoid different stagnant zones in the liquid melt by stirrer. Stirring of the mixture is carried out at different holding time (10, 20, and 30 minutes) to achieve homogeneity of particulates. Effect of the holding time helps in the Al-SiCp composites mainly two ways: to distribute the particles in the liquid, and to create perfect interface bond between reinforcement and matrix. The stainless steel stirrer blade was coated with zirconia to avoid the reaction between stainless steel and Al alloys at higher temperatures. The Argon gas was supplied into the near the crucible during the stirring to avoid the formation of oxide layer on the surface of matrix melt. The Stirring speed 450 rpm was maintained throughout work. The slurry of the composite accordingly prepared was poured the steel moulds. Fig. 5 demonstrates the prepared casting of the metal matrix composite.

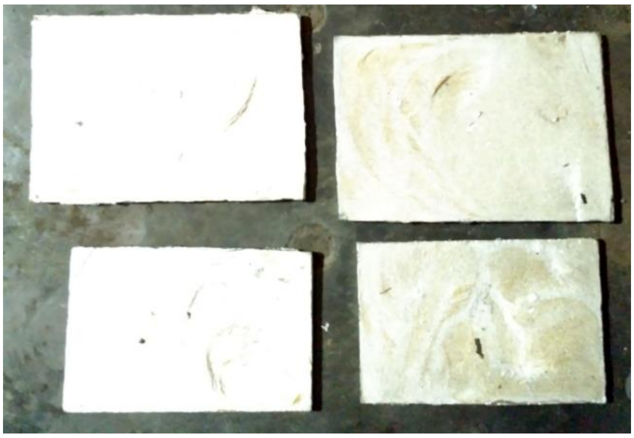

Fig. 5. Prepared 10%SiC Reinforced Al 6061 MMC.

Table 4. Typical Properties of 10%SiC Reinforced Al 6061 MMC

Density, g/cm^3	2.95-3.00
Thermal Conductivity, W/m.k	170-200
Thermal Expansion Coefficient, E-6 k^{-1}	Tailor-made from 6.5 to 9.5
Electrical resistivity, µΩ.cm	30-50
Bending strength, MPa	350-500
Elastic Modulus, GPa	200-230

3.2. 3. Advantages of Aluminium based MMC

The advantages of aluminium based metal matrix composites are [17] [18] [21]:

- High strength
- High stiffness
- Low density (weight)
- Improved properties at high temperatures
- Improved electrical conductivity
- Improved resistance to abrasion and wear
- Low thermal expansion coefficient
- Controlled heating of material
- Light weight
- Improved damping capabilities.

4. Results and Discussion

The effect of processing temperature is illustrated in Fig. 6 where the contact time between reinforcement and liquid Al metal with different temperature.

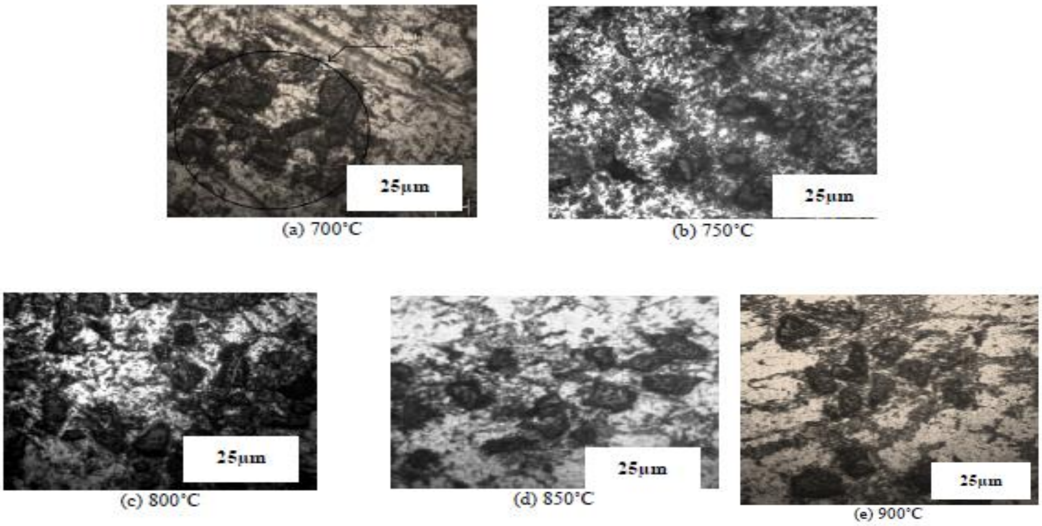

Fig 6. Optical image shows particles distribution at 20 minutes holding time.

Fig. 7 shows the variation in the ultimate tensile strength as a function of temperature is illustrated for Al-10% SiCp composites with different holding time. The ultimate strength of Al-10% SiCp composite has been increased and reached a maximum as the processing temperature changes from 700°C to 800°C, then began decrease with further increase of processing temperature from 800°C to 900°C. These composites exhibited different tensile behaviors. The overall strength of composite is influenced by distribution of particles in the matrix.

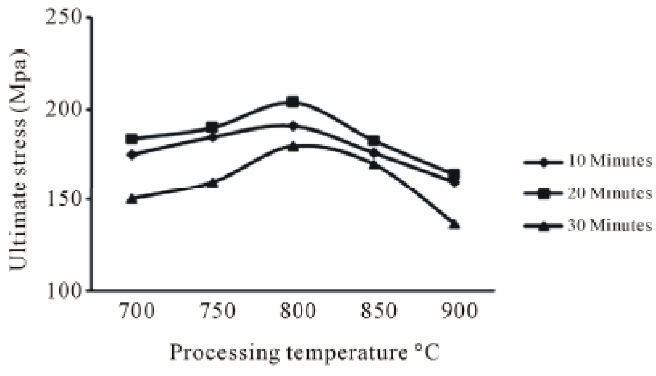

Fig. 7. Effect of processing parameters on tensile strength of Al/SiCp.

The Brinell hardness number was measured along length of the cast specimen at an interval of 1 cm. The low temperature with holding time hardness values at some places is minimum it close to harness values of Aluminium and some places is more. The high values is obtained from the places where the particles is accumulation more and lower hardness values is obtained from places where SiC particles where absent. The Fig. 8 shows the hardness number distributions along length of the cast specimens. The SiC particles added to the aluminium alloy matrix have a satisfactory effect in improving the hardness of the composites.

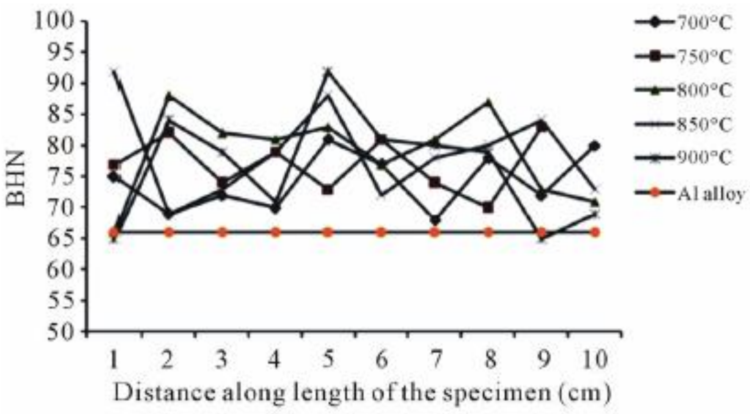

Fig. 8. Effect processing temperatures on Hardness of Al/SiCp.

5. Conclusion

In this research, aluminum as base matrix and SiC as reinforcement in 10% Wt was fabricated using stir casting method by different processing temperatures with different holding time. It is concluded from the microstructure analysis that the particles were distributed uniformly in the processing temperature 750°C and 800°C. The particles agglomerations were found in the processing temperature of 700°C, 850°C and 900°C due to the changes of viscosity in liquid Al matrix. The Ultimate strength of metal matrix composite de-creases with increasing holding time. It is revealed that holding time influences the viscosity of liquid metal, particles distribution and also induces some chemical reaction between matrix and reinforcement. The hardness values increases more or less linearly with increasing of processing temperatures from 750°C to 800°C at 20 minutes holding time.

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