# Characterization of Aluminium Matrix Composites Fabricated Using Different Stir Casting Techniques

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**ABSTRACT**

*A number of fabrication techniques are available for the production of these AMCs and among all these fabrications techniques, stir casting is the most popular route which is less expensive, simple and used for small as well as mass production but the major drawback of this technique is the non-uniform reinforcement particle distribution and agglomeration which forms unwanted brittle phase. In the present work an attempt hasbeen made to fabricate AMCs using AA6063 aluminium alloy as matrix reinforced with ceramic $Al_2O_3$ particulatesusing three different liquid metallurgy route in particular stir casting technique viz. pit furnace manual stir casting, muffle furnace stir casting and bottom pouring stir casting processes to understand the possibility of stir casting process in reinforcement particles distribution.The aim of the present study is to investigate the effect of applied shear stress through stirring on the reinforcement particle distribution. Thecharacterization is carried out for the above prepared AMCsfor mechanical and morphological properties to investigate the best process among the all three used. The results reveals that the bottom pouring stir casting processes produced composites with better properties and more uniform reinforcement distribution when compared to the other two. Choices of the suitable fabrication method is also suggested in this study.*

***Keywords:****Alumina, aluminium matrix composites,mechanical properties, microstructure, stir casting*

## 1. Introduction

Aluminium matrix composites (AMCs) are being extensively used in different engineering and industrial applications replacing conventional monolithic alloys [1] because of their excellent properties like high strength, high stiffness, low density, high fatigue resistance, superior tribological behaviour at elevated temperature etc. [2-5] Selection of a suitable fabrication technique having controlled processing conditions and type of reinforcement particles furtherimproves the mechanical and morphological properties of composites. But sometimes if the particles not distributed uniformly in the matrix phase, brings undesirable changes to the composite properties. Particles agglomeration causes excess brittleness to the composites and is more severe with fine particulate size of sub-microns or nano range. This inhomogeneous distribution of particulates in the matrix generates strain gradient locally and hence also decreases the tensile strength.

The method of fabrication of any particulate reinforced composite has a major role in the homogenous distribution of particles in the matrix. A number of MMC fabrication technique includes stir casting [6], compo casting, powder metallurgy, squeeze casting, die casting [7] etc. Velasco et al. [8] fabricated Al/Fe3Al particles by powder metallurgy technique and reported that the composites exhibited better tensile strength thanthe conventionally forged components. Peng et al. [9] fabricatedaluminium matrix composites by squeeze casting and observedthat the composites reinforced with alumina in the form of performexhibited higher tensile strength compared to that of the aluminafibre reinforced composites. Kok[10] employed vortex methodand subsequently applied pressure to fabricate composites andrevealed that coarser $Al_2O_3$ particles dispersed uniformly in aluminiummatrix, while agglomeration and porosity were observedin composites with finer $Al_2O_3$ particles. But among all the liquid routes of MMC fabrication stir casting technique is widely used in MMC fabrication for industrial as well as research applications[6]. Stir casting route is a simple route of MMC fabrication in which the parameters *viz.* furnace atmosphere, time and speed of stirring, etc. can be controlled more easily when compared to the other liquid routes and these characteristics make this process applicable for mass production. When compared with the other methods of MMC fabrication, it costs around 1/3$^{rd}$ to 1/10$^{th}$ low for mass production [11-12].There are numerous modifications which are applied in the conventional stir casting process so as to improve the process capabilities and the properties of fabricated MMCs. Multi-step mixing includes the stirring of the mixture for two or more time below the liquidus temperature of the matrix for homogenous distribution of reinforcement [13].Intensive shear was also applied to the melt mixture to dis-agglomerate the reinforced particles and break the gas layer present around particles for improving the wetting behaviour with the matrix [2].In case of nano or sub-micron sized reinforced particles electromagnetic stirrers were also employed to improve the particle matrix interface bonding [14]. The presence of inert environment in the melting furnace also improves the composite properties as it prevent the material loses because of oxidation in molten state [15].

Keeping in view the importance and possibilities of stir casting process, three different stir casting methods *viz.* pit furnace manual stir casting process, muffle furnace stir casting process and bottom pouring stir casting process were used to fabricate Al-MMCs. The fabricated MMCs are then characterize for their microstructural and mechanical properties to find that which technique is a better option MMC fabrication.

## 2. Materials and Methodology

In the present work, aluminium AA6063-T6 alloy is used as matrix material and alumina particles ($Al_2O_3$p) with particle size of ≤ 10µm is reinforcement. The composition of AA6063 aluminium alloy is shown in Table 1. The MMC samples are prepared with 10% by weight of $Al_2O_3$p reinforcement.

**Table 1**Composition of aluminium 6063 T6 alloy

| Weight % | Al | Si | Fe | Cu | Mn | Cr | Mg | Zn | Ti | Others |
|---|---|---|---|---|---|---|---|---|---|---|
| AA6063 | 97.5 | 0.2-0.6 | 0.35 | 0.1 | 0.1 | 0.1 | 0.45-0.9 | 0.1 | 0.1 | 0.15 |

### 2.1 Al/$Al_2O_3$ MMC Fabrication

Three different stir casting techniques are used for MMC fabrication *viz.* pit furnace manual stir casting (PFMSC) process, muffle furnace stir casting (MFSC) process and bottom pouring stir casting (BPSC) process. The detailed procedures of MMC fabrication for all the three processes is as follows:

### 2.1.1 Pit Furnace Stir Casting Process

In pit furnace stir casting process aluminium is melted inside a graphite crucible using a pit furnace. This furnace is charged with anthracite coal and have maximum temperature limit of 950ºC. The furnace is having a fan at the bottom which blow air inside it and ignite the coal. Pre-heating of aluminium and $Al_2O_3$p has not been done during this process as there is no separate arrangement for it. The temperature of the furnace throughout the process is between 800ºC to 820ºC as measured from laser thermometer which 0is already above the liquidus temperature of aluminium. After complete melting of aluminium, $Al_2O_3$p is slowly added in it and simultaneously stirred manually with the help of a steel road. The stirring is done five times, every time for more than a minute. The shear force applied to the particles during this manual stirring is the least of all three processes. The mould used in this casting is green sand mould made by using silica sand with liquid jaggerywaste as binder. The pouring is done manually using a crucible tong. After 5 minute of pouring, the casting is dragged out from the mould by breaking it. Figure 1 shows the complete process of MMC fabrication using pit furnace stir casting technique.


**Fig. 1** MMC fabrication using pit furnace**(a)** melting of aluminium **(b)** adding of reinforcement $Al_2O_3$ particulates **(c)** manual stirring through steel rod **(d)** prepared mould **(e)** pouring of molten material **(f)** solidification of molten material **(g)** dragging of solidified MMC **(h)** fabricated $Al/Al_2O_3$ MMC

### 2.1.2 Muffle Furnace Stir Casting Process

Two induction furnaces of different capacities are used in MMC fabrication using muffle furnace stir casting process. The furnace with a capacity of 1200ºC is used for pre-heating and melting of aluminium and the furnace with a capacity of 1000ºC is used for pre-heating of the reinforcement $Al_2O_3$p. In this process the aluminium is pre-heated inside a graphite crucible to a temperature of 450ºC for 1 hour and then the furnace temperature is increased to 750ºC *i.e.* above the liquidus temperature of aluminium to melt it completely. The reinforcement $Al_2O_3$p is pre-heated to a temperature of 500ºC for 1 hour to remove the moisture and hydroxides so as to improve the wettability. After complete melting of aluminium the temperature of the furnace is dropped to 620ºC *i.e.* below the liquidus temperature of aluminium and $Al_2O_3$p is added to the melt. Now the stirring mechanism is installed in the furnace and stirring is started with speed ranging from 300 rpm to 500 rpm for 10 min. The temperature of the furnace is again increased to 700ºC and the stirring is again done for 5 more min at 500 rpm. The purpose of stirring again is to agitate the $Al_2O_3$p and to make their distribution homogenous. Then the crucible is taken out of the furnace using a crucible tong and the molten material is poured in the mould. The mould is made up by joining twohalves of cross-sectionally cutted stainless steel circular pipes joined by using steel wires. This mould is having a steel plate base to which one half part of the pipe is welded. Inside surface of the mould is coated with clay so as to make it non-sticky and for easy removal of the casting after solidification. The mould is placed inside moist sand so as to fix it and for proper cooling of the casting. After 10 min of pouring the casting is taken out by taken out the mould from sand and dissembling it. Figure 2 shows the complete process of MMC fabrication by using muffle furnace stir casting process.

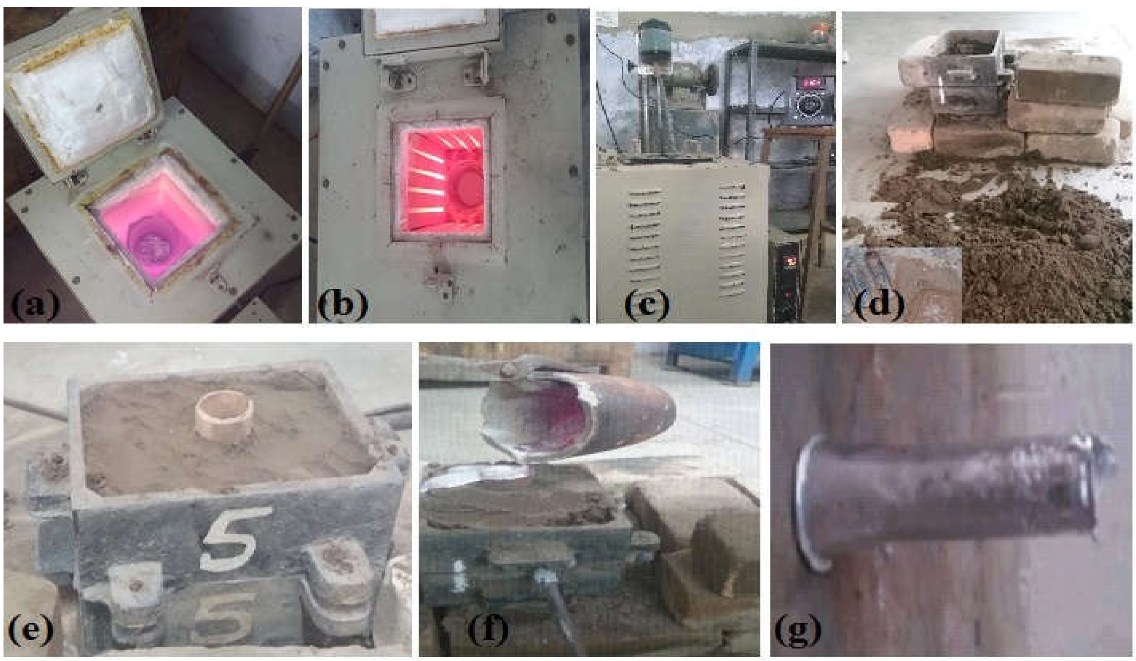


**Fig. 2** MMC fabrication using pit **(a)** melting of aluminium **(b)** adding of reinforcement $Al_2O_3$ particulates **(c)** manual stirring through steel rod **(d)** prepared mould **(e)** pouring of molten material **(f)** solidification of molten material **(g)** dragging of solidified MMC **(h)** fabricated $Al/Al_2O_3$ MMC

### 2.1.3 Bottom Pouring Stir Casting Process

BPSC process is an automatic process, designed to eliminate the number of processing steps as in conventional stir casting processes [16]. This is a simple process whose primary objectives is homogenous distribution of reinforcement by distributive and dispersive mixing. The BPSC machine has a pouring mechanism in which the molten material from the crucible (fixed inside the furnace) is directly poured to the mould without the crucible being taken out of the furnace. This machine also includes two reinforcement particulate chamber having valves for controlled flow and induction mechanism for preheating of reinforcement. These chambers are connected to the crucible fixed inside the furnace. The stirring mechanism of the machine is having controllable speed and motion to facilitate proper stirring. The mould preheater can heat the mould up to a temperature of 450ºC. The mould in current investigation is having a square cross-section with 50 mm side and a length of 250 mm. Figure

3 (e) shows the assembled mould. The rubber washers shown in Fig 3 (e) are used to create vacuum inside the mould cavity.

In BPSC process the temperature is maintained at the same level as that of muffle furnace stir casting process. The aluminium is first preheated at a temperature of 450ºC for 1 hour and then the furnace temperature is increased to 750ºC. The SiC particles is simultaneously preheated in the reinforcement particulate chamber at a temperature of 500ºC to enhance the wettability. As the aluminium melted completely the temperature of the furnace is fixed at 620ºC *i.e.* below the liquidus temperature of aluminium AA6063 alloy so as to make it a semi solid type from its liquid state. The reinforcement $Al_2O_3$p is started pouring through the valve in a very controlled manner with simultaneous stirring at a speed of 400 rpm. After complete addition of $Al_2O_3$p the temperature is again increased to 700ºC *i.e.* above liquidus temperature. The stirring speed is increased to 700 rpm to apply a higher shear force to the agglomerated particles and make a homogenously mixed slurry. After 5 min of stirring the slurry is transferred to the preheated mould in which the vacuum is created already. After 15 minute of pouring the mould is removed and the casting is taken out by dissembling it. Figure 3 shows the utilised BPSC machine and the complete process of MMC casting.


**Fig. 3** MMC fabrication by BPSC**(a)**BPSC machine **(b)** vacuum chamber for mould **(c) &(d)** dimensions of the mould **(e)** prepared mould **(f)** fabricated Al/$Al_2O_3$ MMC

## 3. Characterization and Results

### 3.1 Hardness

The workpiece samples are prepared from casted Al-MMCs for micro-hardness test by polishing on a double disc polishing machine with different grit size emery papers alumina polishing fluid. Vicker Hardness test machine of HUAY IN HV-1000B is used for hardness test. Figure 4 shows hardness testing machine and the residual indentation mark on Al-MMC at a magnification of 200×. The load applied is 200 gm for 15 seconds dwelling time. To confirm the hardness for each fabricated MMC, average of three hardness value from three different places had been taken. The hardness of the MMC fabricated using BPSC process is found to be 79.7 (HV) whereas the hardness value of MMC fabricated using muffle furnaces is 71.8 (HV) and the hardness of MMC fabricated using pit furnaceis 58.3 (HV), which is least among all the three values.

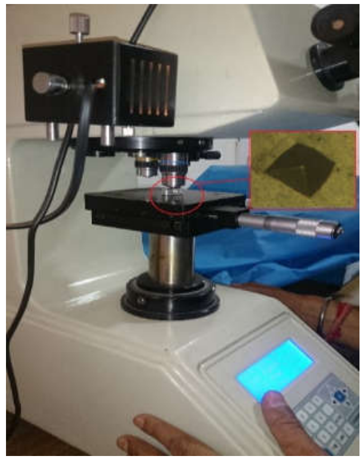

**Fig. 4**Vicker Hardness testing machine of HUAY IN HV-1000B and the residual indentation mark on Al-MMC

## 3.2 Ultimate Tensile Strength

The ultimate tensile strength of the fabricated MMCs has been examined using a universal testing machine 'UTE 40 model' (Fuel Instruments and Engineers Pvt. Ltd.). Figure 5 shows the variation in the tensile strength and elongation with the applied method of fabrication.

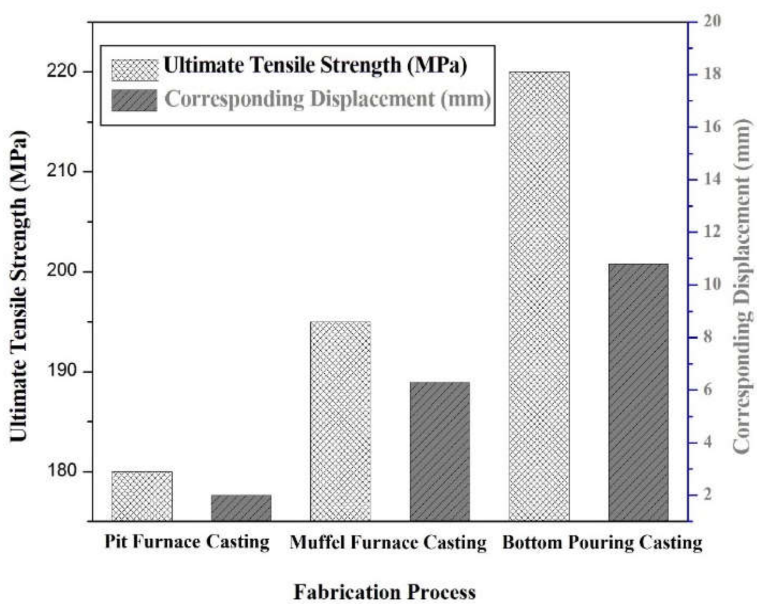


**Fig. 5**Variation of ultimate tensile strength and the corresponding displacement according to the method of fabrication.

The results revealed that the MMC fabricated using BPSC process exhibit highest tensile strength of 220 MPa at a maximum load 22 kN with corresponding displacement of 10.8 mm, muffle furnace stir casted MMC has a tensile strength of 195 MPa at a load of 20 kN with a corresponding displacement of 6.3 mm whereas the pit furnace stir casted MMC has a tensile strength of 180 MPa at a load of 20kN with a corresponding displacement of 2.0mm. The highest strength of BPSC casted MMC is due to the homogenous distribution of reinforced SiC particles in to the matrix and better wetting behaviour of the preheated reinforcement. The elongation in this MMC shows better ductile behaviour when compared with the other fabrication methods. SEM images of the fractured surface of MMC fabricated using BPSC process are shown in Fig. 6.

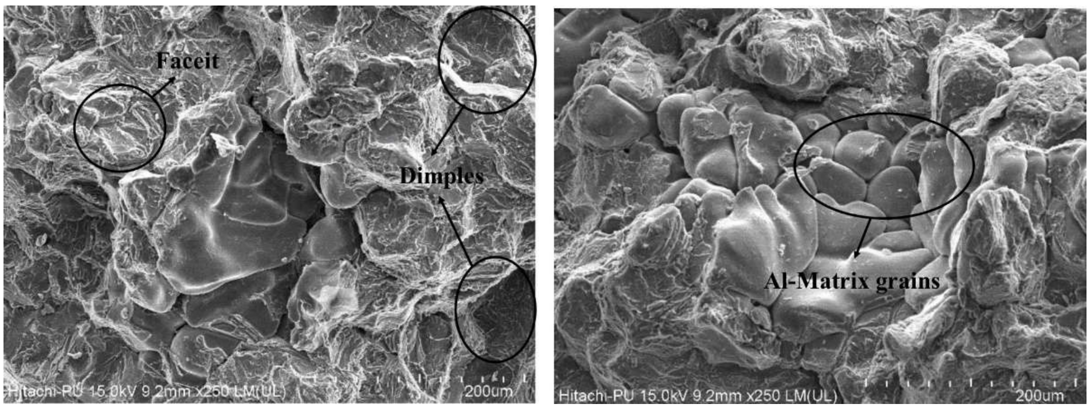


**Fig. 6**SEM images of the fractured surface of BPSC casted MMC sample showing the faceits and dimples representing brittle and ductile fracture respectively and the Al-matrix grains.

### 3.3 Microstructure

Optical micrographic images are used to study the microstructural properties of all the fabricated MMCs. The images are taken at different magnifications using digital optical microscope. The results shows that the BPSC fabricated the MMC with better microstructural properties with almost no porosity and uniformly distributed SiC particles. Figure 7 (a) & (b) shows the microstructure images of the MMC fabricated using BPSC technique. In case of muffle furnace fabrication although the reinforcement distribution is better when compared to pit furnace fabrication but presence of porosity near grain boundaries degraded the quality of composite. The matrix grains are also not closely packed when compare to the BPSC fabrication technique. Figure 7 (c) & (d) shows the microstructure images of the MMC fabricated using muffle furnaces. In pit furnace stir casting technique the reinforcement is not uniformly distributed in the Al-matrix and form particle clusters. The porosities are even more when compared to the other two processes. Figure 7 (e) & (f) shows the micrographic images of the MMC fabricated using pit furnace. Comparing all the microscopic images at different magnifications, BPSC fabricated MMC shows better results when compared to the other two processes.

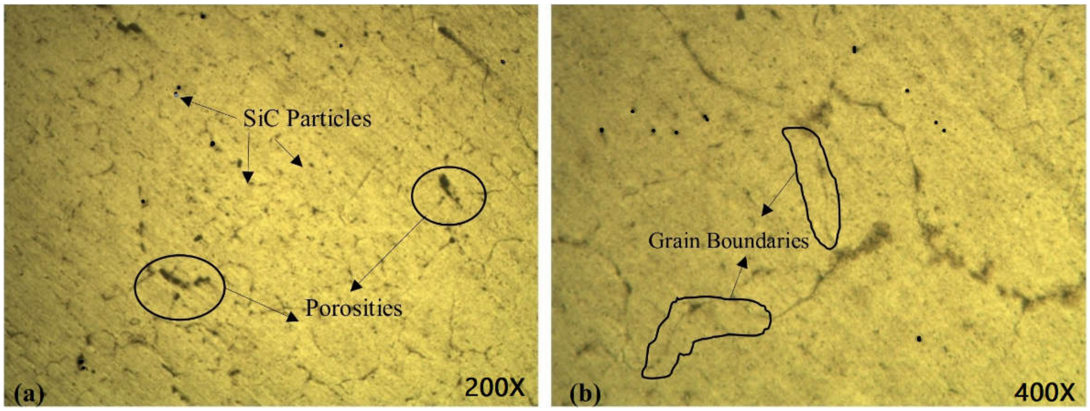


**Fig. 7a,b** Optical microscopic images of all the fabricated MMCs showing grain boundaries, SiC particles, porosity, and particles cluster (a) & (b) fabricated using BPSC furnace

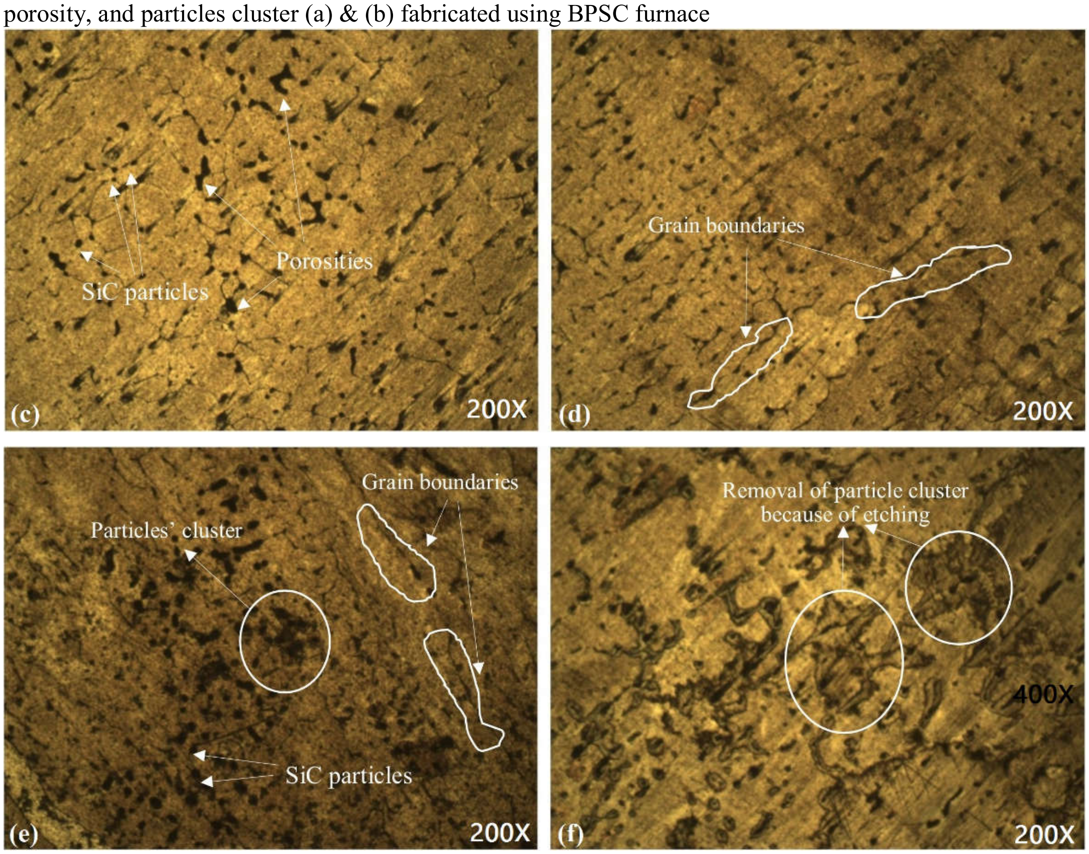


**Fig. 7c,d,e,f** Optical microscopic images of all the fabricated MMCs showing grain boundaries, SiC particles, porosity, and particles cluster (c) & (d) fabricated using muffle furnace stir casting process and (e) & (f) fabricated using pit furnace stir casting process.

## 4. Conclusion

This paper presents the concept of stir casting for MMC fabrication for applying intensive shearing to dis-agglomerate and distribute the reinforcement particles homogenously in the metal matrix. Three different types of stir casting processes *viz.* pit furnace manual stir casting, muffle furnace stir casting and bottom pouring stir casting are used to fabricate the Al/$Al_2O_3$ MMC samples and characterized for their physical and morphological properties. The conclusion of this study is as follows:

- The addition of ceramic reinforcement in Al alloy increased its hardness but it also depends upon the method of fabrication used. The hardness of the MMC fabricated using BPSC process is found to be 79.7 (HV) whereas the hardness value of MMC fabricated using muffle furnaces is 71.8 (HV) and the hardness of MMC fabricated using pit furnace is 63.4 (HV).
- From the tensile testing of the composites it is concluded that the MMC fabricated using BPSC process exhibit highest tensile strength of 220 MPa, MFSC casted MMC has a tensile strength of 195 MPa and PFSC casted MMC has a tensile strength of 180 MPa.
- Results of fractography revealed the presence of both, faceits from brittle fracture and dimples from ductile. The elongation of in case of BPSC fabricated MMC 10.8 mm which is maximum when compare to MFSC casted MMC (6.3 mm) and PFSC casted MMC (2.0 mm).
- From the optical microscopic images it can be concluded that the SiC particles' distribution is more uniform in case of MMC fabricated using BPSC process and the presence of porosity defect is negligible. But in case of MFSC fabrication porosity is very much present and in case of PFSC fabrication porosity as well as particles clusters are present. The reinforcement distribution in case of PFSC is not uniform.

From the results of the above study it is concluded that the BPSC technique is best among the three presented techniques. The Automation applied in this process not only eliminates the various processing steps of the conventional stir casting process but also concerns about the safety of the worker when compare to PFSC and MFSC processes. A composite with better microstructural and physical properties can be produced using this process.

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