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Characterization of Aluminium Alloy 6063 Hybrid Metal Matrix Composite by Using Stir Casting Method

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Abstract**—**The present research is a paper on the characterization of aluminum alloy-6063 hybrid metal matrix composites using three different reinforcement materials (SiC, red mud, and fly ash) through stir casting method. The red mud was used in solid form, and particle size range varies between 103-150 µm. During this investigation, fly ash is received from Guru Nanak Dev Thermal Plant (GNDTP), Bathinda. The study has been done by using Taguchi's L9 orthogonal array by taking fraction wt.% (SiC 5%, 7.5%, and 10% and Red Mud and Fly Ash 2%, 4%, and 6%) as input parameters with their respective levels. The study of the mechanical properties (tensile strength, impact strength, and microhardness) has been done by using Analysis of Variance (ANOVA) with the help of MINITAB 17 software. It is revealed that silicon carbide is the most significant parameter followed by red mud and fly ash affecting the mechanical properties, respectively. The fractured surface morphology of the composites using Field Emission Scanning Electron Microscope (FESEM) shows that there is a good mixing of reinforcement particles in the matrix. Energy-dispersive X-ray spectroscopy (EDS) was performed to know the presence of the phases of the reinforced material.

Keywords**—**Reinforcement, silicon carbide, fly ash, red mud.

I. Introduction

CONSERVATIVE engineering materials are unable to meet the requirement of special properties like high strength and low density materials especially required in aircraft applications. Hence, there is a pronounced requirement for materials with special properties with development of new technologies. Thus, new class of engineering materials emerged, i.e. composites. Any multiphase material that is artificially made and exhibits a significant proportion of the properties of the constituent phases is composite [1]. The matrix phase for a MMC often is a metal which is ductile. MMCs are manufactured with aims to have high strength to weight ratio, high resistance to abrasion and corrosion, resistance to creep, good dimensional stability, and high temperature operability. There are two or more fibers in a hybrid composite which are different from one another in a single matrix phase. Composites possess high resistance to corrosion, chemicals and other weathering agents. High strength to weight ratio (low density high tensile strength) is the special feature of these materials [2].

A hybrid composite possesses better mechanical properties with excellent strength and stiffness.

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II. Stir Casting

In general, 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 [2]. Stir casting setup mainly consists of a furnace and a stirring assembly as shown in Fig. 1. Aluminium is a soft, durable, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. Aluminum is nonmagnetic and non-sparking. Aluminium has about one-third the density and stiffness of steel.

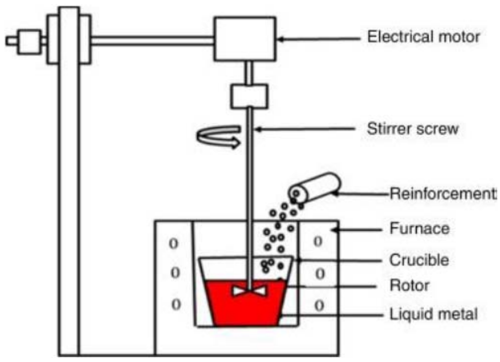

Fig. 1 Stir casting [5]

Harun et al. studied the effect of fly ash particles in Al-4Si-Mg cast composite. The results showed that particle contents affected the presence of porosities and hardness of the composites. It was observed that increasing the fly ash content increases the porosity in the composites; with the matrix alloy reinforced with high wt.% of fly ash particles, they have the highest porosity and lowest hardness [3]. Manoj et al. synthesized the study development of aluminium based silicon carbide particulate metal matrix composite [4]. Sozhamannan et al. studied the effect of processing parameters on metal matrix composites using stir casting process. They fabricated aluminium metal matrix composites which were by different processing temperatures, with different holding time and established that metal matrix particles were distributed uniformly in the processing temperature 750 ˚C and 800 ˚C.

Their other observation was to obtain sufficient wetting of particle by liquid metal and to get a homogenous dispersion of the ceramic particles [5]. Rathod et al. studied the microstructure and mechanical property of aluminium-alumina metal matrix. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. Their work was focused on the study of behavior of Aluminium Cast Alloy (LM6) with and Al_2O_3 composite produced by the stir casting technique. Different % age of reinforcement is used. The results confirmed that the stir formed Al alloy LM6 with Al_2O_3 reinforced composites is clearly superior to the base Al alloy LM6 in terms of tensile strength, impact strength as well as wear resistance [6]. Vikas et al. conducted an experimental study on mechanical properties of metal matrix composite (aluminium based). The results show that the mechanical properties were enhanced by increasing the composition of weight percentage of silicon carbide [7]. Ali et al. dealt with the study on mechanical and tribological properties of Al 6063 MMC reinforced with nano SiC, fly ash, and red mud. The nanoparticles can improve the base material in terms of wear resistance, damping properties and mechanical strength. To achieve this objective, stir casting technique has been adopted and then its mechanical and tribological properties such as tensile strength, impact strength and wear behavior of produced test specimen have been studied. The main aim involved in the present work is focused on study of mechanical and tribological properties of Al 6063 alloy composite having varying weight percentages of 3% - 2% - 2% of nanosized silicon carbide, fly ash, and red mud [8]. Narasaraju et al. characterised the hybrid rice husk and fly ash reinforced aluminium alloy composites. In the present study, an attempt is made to explore the possibilities of reinforcing aluminium alloy (AlSi10Mg) with locally available inexpensive rice husk and fly ash for developing a new composite material. Hybrid rice husk and fly ash particles are added in aluminium alloy matrix at 20% by weight with different proportion using stir casting method. The fabricated cast specimens are characterized with optical and scanning electron microscopes. SEM study validates the presence of rice husk and fly ash in aluminium matrix. The mechanical properties such as tensile strength, percentage elongation, and hardness are studied for all stir-cast specimens [9]. Kaumar et al. performed experiments to study mechanical properties of Al-4.5 wt.% Cu- sic and Al-4.5 wt.% Cu-fly ash composites. In the present analysis, an effort has been made to compare the mechanical properties of Al - 4.5 wt.% Cu Alloy reinforced with SiC and Fly ash by using fluid metallurgy route. Al-4.5 wt.% Cu Alloy was used as the matrix material. SiC and Fly ash particulates were used as reinforcements. A comparative study was carried on mechanical properties of Al-Cu-3 % SiC and Al-Cu-3% Fly ash composites. The microstructure study was carried out using optical microscopy which resulted in uniform distribution of reinforced particles in the matrix alloy. The results indicate that hardness, ultimate tensile strength, and yield strength of the composites were found to be higher when reinforced with SiC compared to Al-Cu base matrix and Fly ash particulates reinforced composites [10]. Jose et al. studied the mechanical and wear properties of Al 7075/ zircon and fly ash hybrid metal matrix composites. The recent studies revealed that the materials must possess better mechanical and metallurgical properties. In their paper, four samples were prepared by using stir casting. The first sample is Al 7075, the second sample consists of Al 7075 with 3% Zircon, the third sample consists of Al 7075 with 6% Fly Ash, and the fourth sample is of Al 7075 with 3% Zircon and 6% Fly Ash. It was found that tensile strength and hardness is increased when zircon and fly ash is added to Al7075. Wear is decreased when zircon and fly ash is added to Al 7075. Microstructure is also studied using scanning electron microscope to understand the wear [11]. Amit et al. in their paper of stir casting technique fabricated Al 2024/red mud MMC. The MMC was developed under the environment of Argon gas using controlled process parameters. The effect of different weight percentage and particle sizes of red mud on the mechanical properties of Al/2024 MMC is reported. Scanning Electron Microscope (SEM) images reveal the uniform distribution of the reinforced red mud particulates in the MMC. XRD examination confirms the presence of red mud particles in the MMC. The results reveal that tensile strength and microhardness of the Al2024/red mud MMC increased with the increasing weight percentage and decreasing particle size of red mud in the MMC [12].

A lot of work has been done on aluminium based metal matrix composite with various types of reinforcement, different size and manufactured techniques either by stir casting or by spray casting technique and then subjected to study the mechanical properties like: tensile strength, micro hardness, and microstructure of the material [13].

It has been observed that very limited work has been performed on the combination of “Silicon Carbide, Fly Ash and Red Mud” as a reinforcement and matrix is Al Alloy 6063. Very little information is available on mechanical properties like: tensile strength, impact strength and micro hardness of composite material after the reinforced by silicon carbide, fly ash and red mud. There is lack of information regarding optimization weight % of reinforcement materials. The combination of silicon carbide, fly ash and red mud as reinforcement in Al alloy 6063 matrix, is studied by stir casting technique. Reinforcement is used in veering weight % Red mud and fly ash 2, 4 and 6% wt. and silicon carbide 5, 7.5, and 10 %wt. The change in physical and mechanical properties will also be taken into consideration. The aim of experiment is to be study the effect of parameters, as percentage composition, corrosive medium and physical and mechanical properties of the metal matrix composites. The experiment will be carried out by preparing the sample of different percentage composition by stir casting technique and then it is subjected to the corrosive medium, predicting the change in properties of metal matrix composites.

III. Reinforcement Material

Red mud was used as a reinforcement material. The red mud was used in solid particle form with size range 103-150 μm. This is achieved with the help sieve shaker. Silicon carbide was used as reinforced material. SiC was in the powder form whose size varies between 63 and100 µm. In the present research work, fly ash collected from G.N.D.T.P Bathinda has been used as a reinforcement material. Fly ash is waste product of coal based thermal power plants. This is done by sieving the collected fly ash powder in universal sieve shaker machine having sieves of many micron levels.

IV. Design of Experiment

Taguchi method is one of the most powerful designs of experiments to understand process characteristics and to investigate how experimental parameters affect the final responses based on statistical backgrounds. In addition, it has been used to systematically determine the optimal process parameters with fewer testing trials. A well designed experiment can reduce substantially the number of experiments required [14]. Three reinforcement materials are considered as controlling factors. They are silicon carbide, fly ash and red mud. Each factor has three levels – namely low, medium and high respectively. According to the Taguchi method, for three factors and three levels for each parameters L9 orthogonal array should be employed for the experimentation. Table I shows the reinforcement materials factors and their levels considered for the experimentation.

TABLE I
Factor and Their Levels

S No.	Factors	Level 1	Level 2	Level 3
1	Sic	5	7.5	10
2	Fly Ash	2	4	6
3	Red Mud	2	4	6

Table II shows the Taguchi orthogonal array selector which shows the orthogonal array for the parameters and levels. For three factors and three levels, L9 orthogonal array was selected from the array selector. It is prepared by Minitab 17 Software. It is further used for the optimization of parameters.

V.MMC Preparation by Stir Casting Route

A stir casting setup consisting of a resistance Muffle Furnace and stirrer assembly was used to synthesize the composite. Approximately, 1 kg of alloy in solid form was melted at 820 ºC in the resistance furnace. Preheating temperature and time of reinforcement red mud, sic and fly ash was kept at 350 ºC and one, respectively. A constant speed of the stirrer 450 rpm was maintained, and preheated reinforced particles were added with a spoon in the molten metal. After the addition of reinforcement, stirring was continued for 8 to 10 minutes for proper mixing of prepared particles in the matrix. The melt in the crucible for approximate half minute in static condition, it was poured in the mould. Stir casting process parameters are constant, and they are shown in Table III.

VI. Material Characterization

The tensile tests are performed as per ASTM 370A standards. The tests are conducted using a Universal Testing Machine (UTM) available in Research lab (Department of Mechanical Engg. GZSCCET Bathinda). Three samples of each composite are tested, and their mean values are taken. Tensile strength has been calculated by the formula: S= F/A where F is the maximum load (in newton) and A is the area of the specimen. Microhardness was also calculated by using MVH-II hardness tester, Vickers microhardness testing machine available at Research Lab Research lab (Department of Mechanical Engg. GZSCCET Bathinda) is used to determine the microhardness of the composite. The load applied is 200 gms for a period 20 sec. For each specimen, three reading have been taken to calculate the Vickers hardness number, and then, their average is considered.

TABLE II
Taguchi Orthogonal Array Design - L9

S. No	Silicon Carbide	Red Mud	Fly Ash
1	5	2	2
2	5	4	4
3	5	6	6
4	7.5	2	4
5	7.5	4	6
6	7.5	6	2
7	10	2	6
8	10	4	2
9	10	6	4

TABLE III
Stir Casting Parameters

S. No	Parameter	Level
1	Casting Temperature	820 °C
2	Stirring speed	450 rpm
3	Reinforced Material Preheated	350 °C
4	Stirring Time After Reinforced Material Added	8-10 min

The machined and fractured surface of the test specimens have been analyzed using FESEM of Carl Zeiss, Germany Model: Merlin Compact installed at Central University of Punjab, Bathinda. The specimens are viewed at an accelerating voltage of 20 kV. The SEM micrographs are clicked at 50X to 2000X. The specimens are two types machined surface and fracture surface. The machined surface specimens are finished by using empery paper of grade 250, 320, 60, 800, 1000, 1200 and 2000.

VII. Results and Analysis

The effect of the various parameters like silicon carbide, red mud, and fly ash weight % on the desired mechanical properties is also discussed here using ANOVA technique on MINITAB 17 software. The observed values of tensile tests along with their S/N ratio obtained during Anova Analysis in Minitab 17 software. All the samples casted were subjected to tensile loading using a computerized UTM testing machine as per the ASTM E-8 standards. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of experimental errors at specific confidence levels. In the present work, 95% confidence level is taken. From the results, it is observed that the weight % of silicon carbide, red mud and fly ash are the parameters affecting tensile strength that can be seen from Figs. 2 and 3.

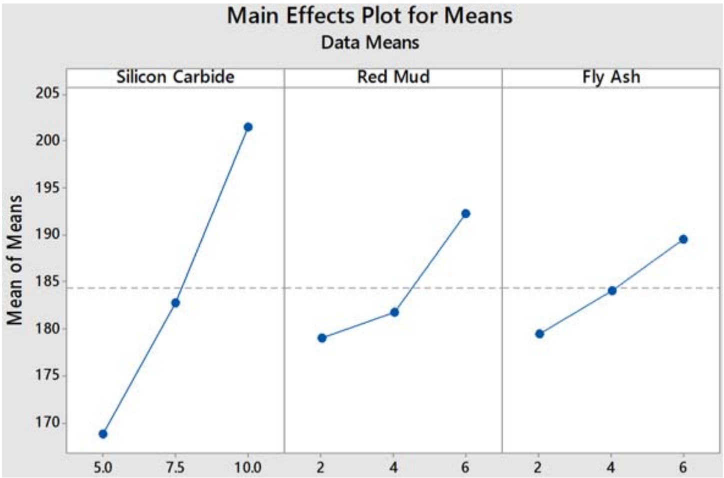

Fig. 2 Main effects plot for tensile strength N/mm^2

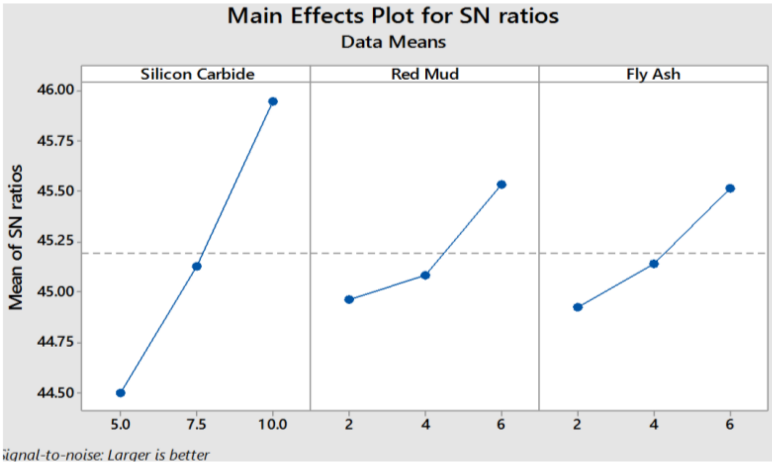

Fig. 3 Main effects plot for sn ratio

It is clear that the all the three parameters are significant and silicon carbide is the most significant parameter followed by the red mud and fly ash affecting the tensile strength respectively. Further as the silicon carbide weight from 5% the tensile strength increased by small extent and reached at 170 n/mm^2 and thereafter significantly increases wt.% from 7.5% and 10% the strength increase 180 n/mm^2 to 205 n/mm^2, respectively. This may be due to more energy transfer to the silicon carbide by the matrix and SiC particles responsiable for increasing ultimate tensile strength by acting as barrier to dislocations in the microstructure.

VIII. Conclusion

The conclusions drawn from the present investigation are as follows:

- Aluminium based metal matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of silicon carbide, red mud and fly ash particulates.
- For synthesizing of composite by stir casting process, stirrer design and stirrer position, stirrer speed and time, particles preheating temperature, particles incorporation rate etc. are the important process parameters.
- The optimum combination of parameters as per ANOVA analysis is found that 10 wt.% of silicon carbide and 6 wt.% of red mud and fly ash for achieving best results in relation to tensile strength.
- The results indicate that the addition of SiC, red mud and fly ash results in increase in tensile strength.
- Red mud and fly ash, the wastage production can be successfully used as a reinforcing material to produce metal-matrix composites (MMCs). It can be replaced by other expansive reinforcement materials.

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