Development and Characterization of AA2024/SiC/Gr/Fly ash Hybrid Composite

Anil kumar\textsuperscript{1,a}, Kapil Kumar Goyal\textsuperscript{1,b}, Arvind Bhardwaj\textsuperscript{1,c}, Neeraj Sharma\textsuperscript{2,d}

\textsuperscript{1}Dr B R Ambedkar National Institute of Technology, Jalandhar
\textsuperscript{2}MMDU Mullana, Haryana, India

E-mail: \textsuperscript{a}anil13544kumar@gmail.com, \textsuperscript{b}goyalkk@nitj.ac.in, \textsuperscript{c}bhardwaja@nitj.ac.in, \textsuperscript{d}neeraj.sharma@live.com

Abstract. The use of hybrid composites now a days has been very attractive due to their light weight, low cost along with high strength to weight ratio. Lot of research is going on to develop the newer composites with improved mechanical, tribological and thermal properties. From the last two decades, Aluminium alloys have gained lot of attention owing to their practical usage and the ease of processing. Aluminium matrix composites are most versatile materials which has applications in advanced structure, aviation, marine and defence application due to their excellent properties. It is a known fact that stir casting is one of the economical method of fabrication of the metal matrix composite, moreover it is also easy to fabricate the composites by stir casting rather than other processes of fabrication. But, the quality of metal matrix composites being cast through stir casting route are highly dependent on the process parameters and achieving the homogenous distribution of reinforcement is a big challenge. In the present investigation, AA2024/SiC/Gr/flyash hybrid composites were fabricated with the stir casting technique (having reinforcement weight composition of SiC 10%, Graphite 5%, and fly ash 5%). The morphological characteristics of the developed Metal matrix composite (MMC) have been investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM). The uniform distribution of the reinforcement particles clearly depicts the development of homogeneous composite.

Key words: Hybrid metal matrix composite, SEM, XRD

1. Introduction

In recent years, lot of work and study has been conducted in the field of advancement of material. In case of advancement of materials, the composites come into the picture.

Composite materials are formed with two or more dissimilar metal/alloy and achieve the new set of properties like strength, hardness, wear characteristics etc. Metal matrix composites (MMCs) recently used in cylinder liners, brake drum, crank shaft, aerospace and automotive industry due to their good strength to weight ratios and their temperature resistance\cite{1}. Aluminium alloy 2024 widely used in aircraft structure, especially wing and fuselage structure under tension\cite{2}. Now a day’s aluminium metal matrix (AMMC) has been steadily improved with their engineering properties like an improved specific strength, stiffness, wear resistance, density etc. The strength and wear resistance of the metal matrix
composites is increased by adding the reinforcement particles such as silicon carbide, graphite etc. Graphite improves the machinability of the hybrid aluminium composites.

Aluminium alloy possess excellent corrosion resistant property, good ductility and hence are non-toxic in nature[3]. Melting range of aluminium alloy (AA) is lies between 482°C-660°C, depend on the alloy and theoretical density of Al2024 is 2800 kg/m³.

The series of aluminium alloy i.e. 2000, 5000, 6000 and 7000 are the most regularly utilized for composites creation yet these compound have low resistance from wear.

The pure aluminium metal is although a light weight material but lacks in the hardness and tensile strength which is most in airplane and helicopter[4]. So, there are many problem of metal/materials related to mechanical properties etc that is not fulfil the required criteria, which is overcome by developing new metal matrix composites material or enhancing the properties of metal matrix composites which is already developed. To establish the compatibility within the used reinforcement and the basic matrix of MMCs, metal alloys are induced, which act as solvent and reinforcements act as solute.

The most commonly used reinforcements in the MMCs are SiC (Silicon carbide), Al₂O₃ (Alumina), graphite, WC (tungsten carbide), B C (Boron carbide), flyash, molybdenum disulphate etc[5]. Fly ash is having low density and low cost reinforcement used in the composites to impart resistant to damage from normal wear. It is available in huge quantities as solid waste by–product after burning of coal in thermal power plants. In India the coal combustion products are produced during 1995 are approx. 90 million tons which has now increased to 140 million tons during the period of 2020[2]. Thus, the fly ash is low cost reinforcements in comparison to the TiC, B₄C and Al₂O₃[6].

Hybrid metal matrix composites with Aluminium as base matrix are widely produced nowadays because of its low cost and better mechanical properties[7]. Researcher from all over the world focusing on the aluminium, due to good mechanical properties and improved corrosion resistance[8]. But still there is scope of research in the field of hybrid composite development and characterization. Therefore, AA2024/SiC/Gr/flyash based hybrid composite is developed by stir-casting method in the present work. The morphological characteristics of developed composite are investigated using X-Ray diffraction (XRD), SEM, and EDS.

2. Materials

2.1 Aluminium (Al) 2024

In the present investigation, Aluminium alloy 2024 is considered as a metal matrix, which has its multiple applications in the field of automotive, aerospace & defence. In Al2024 major alloying elements are copper and magnesium which possess good machinability and better mechanical properties.

| Elements       | Contribution (%) |
|---------------|------------------|
| Copper (Cu)   | 4.29             |
| Magnesium(Mg) | 1.29             |
| Silicon (Si)  | 0.07             |
| Iron (Fe)     | 0.2              |
| Manganese (Mn)| 0.54             |
| Zinc (Zn)     | 0.03             |
| Titanium (Ti) | 0.06             |
| Chromium (Cr) | 0.01             |
| Aluminium (Al)| Remaining        |
Table 2. Composition of Reinforcement material (Wt. %)

| Contribution     | %  |
|------------------|----|
| Silicon carbide  | 10 |
| Graphite         | 5  |
| Fly ash          | 5  |

2.2 Graphite
Graphite particles are good dry solid lubricant and results in low coefficient of friction. Hence, graphite reduces wear & abrasion and impart high strength & stability.

2.3 Fly ash
Fly ash is the low density and inexpensive reinforcements which is available as a by-product of coal after burning in various industrial and power sector applications[9]. Flyash is additionally called as “pulverized fuel ash” and it incorporates extensive measure of aluminium oxide (Al₂O₃), Silicon dioxide (SiO₂), & calcium oxide (CaO). Fly ash in Aluminium composite diminishes cost, reduce density as well as increment in hardness, wear, stiffness, & abrasion resistance.

2.4 Silicon carbide
Silicon carbide (SiC) is an abrasive material which has low density and increases the both mechanical strength and wear resistances of the MMCs. The density of silicon carbide is 3.22 g/cc and it presents thermal shock resistance and high temperature strength. The particle size distribution in the SiC rages from 17-20 μm is desirable for the development of MMCs[10]. Silicon carbide is formed by electro-chemical reaction of carbon and sand at high temperature [2]. Upto 800°C temperature, any acid, alkali or molten salt do not attack on the silicon carbide.

3. Experimental procedure

3.1 Stir casting methodology
To fabricate the composite material, the stir casting technique is being used. In this, the matrix alloy is Al 2024 and rest are the three different reinforcement particulates i.e. graphite, Sic and Fly ash. In the stir casting method, the mechanical stirrer (Graphite) is used to mix the reinforcement with the base metal to make the uniform mixture.
Figure 1. This figure shows Stir casting Setup

Here, layout of the stir casting apparatus is shown in the above figure 1. This layout contains crucible made of graphite and of cylindrical shape which is utilized for production of Aluminium metal matrix composites as it withstands high temperature. Since graphite is non-reactant to aluminium at this temperature range so there is not any possibilities of chemical reaction between aluminium and graphite. In the stir casting process first of all in the muffle furnace, the empty graphite crucible is placed followed by the heating at a temperature of 500°C and then steadily increase up to 900°C temperature to remove moisture present inside the furnace. Then reinforcement’s graphite, SiC and flyash is preheated about 1000°C, 1000°C and 600°C for two hours respectively. The higher temperature of the muffle furnace attained in the beginning contributes to the fast melt down aluminium alloy, which leads to the reduction in the oxidation of molten metal and also helps in dissolving the added reinforcement attributed to the increase in wettability. Then the desired base metal for the metal matrix composite is put in the crucible for further melting.

Now, the Aluminium alloy is heated at 760°C (liquidus temp.) where metal is completely melted. At this point of time, vortex is created using mechanical stirrer and while stirring (200 rpm) is in progress, now add preheated particulates of Silicon carbide, graphite & fly ash. It is ensured that there is constant and smooth flow of particulates addition in to vortex, and melt is covered under the argon gas. Stirring is continued for 3 min to confirm that uniform distribution of reinforced particulates taking place. This experiment results in better mixing of the melt and finally casted composite is obtained.

3.2 SEM Analysis

Scanning electron microscopy (SEM) analysis has been carried out to check the distribution of particulates with the matrix alloy. SEM also provide better visualization of microstructure of MMC. Before performing the SEM, the sample of composite is grinded with the help of abrasive paper and polished by polishing machine. After that, these sample are dipped in etchant solution for 30 sec.

3.3 XRD Analysis

XRD is a strategy principally utilized for phase recognizable proof and in this the collimated x-ray beam are coordinated onto the workpiece [11]. As the workpiece and detector is rotated, the intensity of the reflected X-rays is detected. In present work, the X-rays filtering is carried out in between of the 20 and 80 degree angle. The scanning speed/checking pace of 2 degree/min was utilized in this work.

4. Results and discussion

4.1 Microstructure of Composite

Figures 2–4 shows the SEM images of Composite. The SEM images make sure that reinforcements are uniformly distributed through-out the whole matrix and makes good bond between matrix & reinforcement material which results in better load sharing from matrix to the reinforcement particulates. It shows that hardness is associated with the low porosities of metal matrix composite.

4.2 XRD Analysis

The XRD analysis of the developed hybrid composite is presented in figure 5. The high energy count corresponding to peaks reveals the presence of aluminium while small peaks present carbon particle as reinforcements. Due to the large amount of carbon particles the energy counts in XRD found to be increased. The peaks show the distribution of particles and the bottom of graph show the irregular pattern in the distribution of reinforcement material. The XRD results reveal the presence of compound i.e. Al, silicon which is marked as blue lines in the figure 5 and green colour lines show the presence of Graphite compound in the composite.
Figure 2. (SEM image with 15.0kV with x50)

Figure 3. (SEM image with 15.0kV with 100x)

Figure 4. (SEM image with 15.0kV with 200x)
Figure 5. The XRD pattern of Al matrix hybrid composite for the several weight percentage of SiC-graphite-fly ash content.

5. Conclusion:

In this work, the hybrid metal matrix composite is made using Al2024 as base alloy and silicon carbide, graphite, and fly ash as reinforcement material. After fabricating the hybrid metal matrix composites, various conclusion were drawn:

1. The Hybrid composites of AA2024-FA-SiC-graphite are casted by the stir casting technique successfully.
2. SEM images shows the uniform distribution of SiC-Graphite-Fly ash particles and strong bonding with the base aluminium metal matrix.
3. In the SEM images, the porosity defects present in the metal matrix composite are visualised clearly.
4. The XRD results show the presence of different compound presented in the finally prepared composite. Presence of Aluminium and silicon compound is represented by blue line as shown in the XRD graph, and presence of graphite compound is represented with the green colour line.

Scope of future work

The study can be extended by varying weight composition of reinforcements with Al2024. Wear test, mechanical properties and corrosion behaviour can also be carried out.
References:

[1] Maurya M, Maurya NK, Bajpai V 2019 Effect of SiC reinforced particle parameters in the development of aluminium based metal matrix composite. EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy. Vol; 6:200.

[2] Boopathi MM, Arulshri KP and Iyandurai N 2013 Evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites. American journal of applied sciences vol; 10(3):219.

[3] Kumar KS, Ratnam C, Nagababu B 2019 Fabrication and Mechanical Behavior of Al 2024-B4C MMCs And Al 2024-B4C-Gr Hybrid Mmcs through Po+wder Metallurgy Technique. Materials Today: Proceedings. Vol; 1;18:219-29.

[4] Nair SS and Faisal MH 2016 Fabrication of LM6/B4C/Gr Hybrid Aluminium Metal Matrix Composite. Journal for Research| vol; 2(07).

[5] Kumaraswamy HS, Bharat V and Rao TK 2019 Influence of Boron Fiber Powder and Graphite Reinforcements on Physical and Mechanical Properties of Aluminum 2024 Alloy Fabricated by Stir Casting. Journal of Minerals and Materials Characterization and Engineering vol; 7(03):103

[6] Selvam JD, Smart DR and Dinaharan I 2013 Microstructure and some mechanical properties of fly ash particulate reinforced AA6061 aluminum alloy composites prepared by compocasting. Materials & Design vol; 49:28-34.

[7] Kumar KP, Krishna MG, Rao JB and Bhargava 2015 NR. Fabrication and characterization of 2024 aluminium–High entropy alloy composites. Journal of Alloys and Compounds vol; 640:421-7

[8] Hemalatha K, Kumar LK and Venkatachalapthy VSK 2016 Characterization and Corrosion Analysis of Al 7075 Hybrid Metal Matrix Composite Materials by Stir Casting Method. Journal of Material Science and Mechanical Engineering vol; 3:401-6

[9] Rao JB, Rao DV, Murthy IN and Bhargava NR 2012 Mechanical properties and corrosion behaviour of fly ash particles reinforced AA 2024 composites. Journal of composite materials vol; 46(12):1393-404.

[10] Balasubramanian I and Maheswaran R 2015 Effect of inclusion of SiC particulates on the mechanical resistance behaviour of stir-cast AA6063/SiC composites. Materials & Design (1980-2015) vol; 65:511-20.

[11] Vanam JP and Rao KN 2018 Characterization and Tribological Behaviour of Aluminium Metal Matrix Composite. Jaya Prasad Vanam Journal of Engineering Research and Application Vol; 8(9):6-11.