Mechanical behaviour of fly ash/SiC particles reinforced Al-Zn alloy-based metal matrix composites fabricated by stir casting method

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In the present work Al-Zn/fly ash/SiC reinforced composites are fabricated through vortex method using stir casting route. Fly ash is abundantly available in thermal power plants which is considered to be a major industrial waste. This paper reports the microstructural evaluation and mechanical behaviour of aluminium-zinc alloy reinforced with fly ash and silicon carbide (SiC) has been investigated. Composites reinforced with fly ash and SiC in different weight percentages varying from 0 - 10 wt percentage with a particle size of 53 μm were prepared. The prepared composites were characterized using optical microscope, scanning electron microscope (SEM), Electron back scattered diffraction(EBSD) and tensile testing machine. The microstructural studies revealed the presence of fly ash and SiC particulates and are distributed uniformly throughout the matrix whereas the grain size refinement is observed in EBSD analysis. The incorporation of fly ash particles enhanced the hardness and tensile properties like ultimate tensile and yield strengths were improved by the addition of SiC particles. The strengthening mechanisms were discussed for the improved properties.

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1. Introduction

The ceramic reinforced aluminium matrix composites have drawn significant attention in aerospace, defence, automobiles and other important structural applications as light weight and fuel efficient advanced materials for various applications [1,2]. Metal matrix composites are propelled materials, which consolidate metallic grid with hard ceramic reinforcements, for example, SiC, B4C, TiC, Al2O3 or soft reinforcement to fabricate composite materials [3]. MMC’s have the combined physical and mechanical properties of the alloy matrix and the reinforcements. The aluminium metal matrix composites (AMC’s) have the higher estimation of specific strength, stiffness, wear resistance, fatigue, corrosion and creep depending upon the reinforcement blended and volume fraction of the reinforcement compared with base metal. Such
enhancements of properties lead to AMC’s are playing vital role in aviation, space industry and automotive industry [4].

V. Ramakoteswara Rao et al. studied the tensile behaviour of Al-Zn alloy reinforced with TiC particles, from the results it is concluded that the tensile and wear properties are enhanced with increase in TiC particulates and frictional coefficient decrease with increasing the sliding velocity and weight fraction of TiC [5].

Baradeswaran et al. studied the tensile and tribological properties of AA 7075/Al2O3/graphite hybrid composites and concluded that the frictional coefficient of AA 7075 decreases with the addition of 5 wt. % of graphite and 2,4,6 and 8 wt.% of Al2O3[6].

This work is mainly focused on examining the microstructural analysis and grain structures of hybrid particle reinforced composites with Al-Zn alloy AA7075 which has not been studied so far yet. Thus, in this work the effects of hybrid particle reinforced on the mechanical, microstructures as well as grain refinements of the particulate reinforced composites are reported at room temperature.

2. Materials and methodology

Al-Zn alloy (A7075) was used as matrix material procured from amex resources private limited, Mumbai, India. The composition of the base metal is shown in Table 1. The matrix was reinforced with fly ash and SiC, the fly ash is collected from Vijayawada thermal power station, Vijayawada and SiC is purchased from krish met tech private limited Chennai. The chemical compositions were shown in Tables 2 and 3.

2.1. Selection of composition

The composition selection of fly ash and SiC is made from the available literature and based on the results from their investigations as shown in Table 4. The fly ash and SiC reinforcement percentages vary from 0 to 15% in matrix material taken by weight fraction. If the increase in reinforcement is more than 15% there will be least effect on chemical and physical properties of composites.

2.2. Hybrid composites fabrication

Fig. 1 shows the experimental set up for the fabrication of hybrid composites with Al-Zn based alloy reinforced with fly ash and silicon carbide Al-Zn alloy (A7075) were loaded in muffle furnace and heated to above its liquidus temperature. The molten metal is then poured into a cast iron die in cylindrical form with dimensions of 18 diameter and 90 mm length. The various proportions of fly ash and SiC particulates with an average particle size of 53 μm are reinforced in base alloy using stir casting route. The particles were added in the middle of the vortex by maintaining uniformity in flow to avoid the agglomeration. The amount of FA and SiC were varied from 0 to 15% weight. The argon gas is used as shield over the melt to avoid the oxidation for alloy and composites. All the fabricated specimens were homogenized at 100 °C for 24 h [7]. Praveen kumar et al. has used the similar temperature for homogenization. A number of trails were carried out for selection of speed of stirrer, time taken and temperature and finally a speed of 450 rpm is selected for smooth flow of particles.

2.3. Density studies

The Archimedian’s principle is used to determine the densities of alloy and composites. The main constituents of fly ash include SiO2 (density = 2.19 g/cc), Al2O3 (density = 3.96 g/cc) and Fe2O3 (ρ = 4.88 g/cm³). The fly ash density is supposed to be 1 g/cc. The theoretical values of densities for base alloy and composites are considered using a rule of mixtures [8]

ρcomposite = V1 ρ1 + (1 − V1) ρm

3. Results and discussion

3.1. Microstructural analysis

The SEM micrographs for fly ash and SiC particles are depicted in Fig. 2(a) and (b), the fly ash particles are found in spherical shape and crystal structure is observed in SiC.

The microstructure of Al-Zn base alloy, Al-Zn alloy/fly ash/SiC hybrid composites in different reinforcement

| Table 1 – chemical composition of A7075 alloy. |
| Zinc | Cu | Mg | Si | Cr | Mn | Fe | Pb | Sn | Ti | Al |
| 5.3 | 1.1 | 2.1 | 0.4 | 0.18 | 0.3 | 0.5 | 0.029 | 0.012 | 0.2 | balance |

| Table 2 – chemical composition of flyash. |
| SiO2 | Al2O3 | Fe2O3 | TiO2 | CaO | MgO | Na2O | K2O | Ignition loss |
| 58.4 | 30.40 | 8.44 | 2.75 | 1.3 | 1.53 | 1.0 | 1.98 | 2.45 |

| Table 3 – chemical composition of SiC. |
| Si | Fe | Cu | Mn | Mg | Zn | Ti | Aluminium |
| 6.4 | 0.2 | 0.2 | 0.1 | 0.25 | 0.1 | 0.1 | Balance |
Table 4 – Composition of hybrid-composites.

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Sample nos.</th>
<th>Composition of reinforcements</th>
<th>Silicon carbide (SiC) wt.%</th>
<th>Fly-ash wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample 1</td>
<td>A7075</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Sample 2</td>
<td>A7075 + 2.5% SiC + 2.5% fly-ash</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>Sample 3</td>
<td>A7075 + 5% SiC + 5% Fly-ash</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 1 – (a) Stir casting (vortex). (b) Casted fingers.

Fig. 2 – (a) SEM micrograph of fly ash particles. (b) SEM micrograph of SiC particles.

Fig. 3 – (a) Microstructure for alloy at 100 x. (b) Microstructure for 5% composite at 100 x. (c) Microstructure for 10% composite at 100 x.
percentages were observed through optical microscope as shown in Fig. 3(a–c). The microstructure of alloy shows interdendritic network without any voids shown in Fig. 3(a). Fig. 3(b and c) shows the microstructures of Al-Zn/SiC/fly ash hybrid composites with interdendritic network with uniformly distributed SiC and randomly dispersed secondary phase particles and no evidence of crack formation and porosity are found in the castings. This may be due to incorporating the proper process parameters employed for the production of castings.

3.2. Energy Dispersive Spectroscopy analysis

The Energy Dispersive Spectroscopy analysis (EDS) is conducted for both alloy and composites. The existence of aluminium, zinc and magnesium in the base alloy is depicted in Fig. 4, whereas for composite, the existence of constituents in fly ash and SiC are seen clearly in Fig. 5. It is also evident that the increments in Cu and Mg concentrations are not seen which exposes the dissolution of fly ash and SiC reinforcements was limited to vicinity. The traces of oxygen are not seen in both alloy and composites as the argon gas shielding is perfectly maintained and no contamination has occurred.
3.3. XRD analysis

The XRD, used to verify the mineralogical constituents, was carried out in a Sheifert Model URD 65, X-ray diffractometer operating with Cu-Kα radiation for a 2θ variation from 5° to 65°. Fig. 6 exhibits a mineralogical composition comprising X-ray diffraction patterns of fly ash particulates, the presence of alumina Al₂O₃, Mullite 3Al₂O₃2SiO₂, silica SiO₂, and hematite are seen. The peaks which are represented with miller indices are corresponding to the characteristic peaks of the flyash (ICDD CARD No: C-00-056-0159). The other peaks may be due to other phase of any precursor materials or impurities or may be due to any form of intermediate phase. The average particle size calculated by Scherrer’s formula is 9.006 Å.

3.4. Studies on density and hardness

The densities of base alloy and composites were studied considering average values, the variations in densities are depicted in Table 5 and graphical representation is given in Fig. 7.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Specimen</th>
<th>Density (g/cm³)</th>
<th>Theoretical</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Al-Zn matrix</td>
<td>2.82</td>
<td>2.82</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>2.5%FA + 2.5% SiC composite</td>
<td>2.59</td>
<td>2.54</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>5%FA + 5% SiC composite</td>
<td>2.50</td>
<td>2.45</td>
<td></td>
</tr>
</tbody>
</table>

Densities for composites were found decreased when related to the base alloy and this may be attributed due to the low-density levels of the fly ash. The theoretical densities were compared with measured ones.

Vickers micro hardness studies were carried out for the polished samples of Al 7075 alloy and its composites using UHL IMS 4.0 Vickers Micro Hardness Tester with 500g load. The indentation time for the hardness measurement was 15s. A micrograph revealing the aspect of indentation is shown in Fig. 8. An average of six readings was taken for each hardness value at different locations to circumvent the possible effects of particle segregation. The Vickers hardness number for composites reinforced with fly ash and SiC were found to be increased when compared to the base matrix, the improvement in the hardness may be attributed to the presence of rigid and tough Al₂O₃ and Si present in the fly ash and silicon carbides. Also, the refinement in grainsize is also one of the reason for the improvement in hardness. Similar results were reported by several authors [9,10]. The hardness of a material is a physical parameter indicating the ability of resisting local plastic deformation.

The hardness was increased from 102 VHN for Al-Zn alloy to 120 and 125 VHN for composite 1 and composite 2 as shown in Fig. 9. This could be due to the presence of fly ash particulates which consists of majority of the alumina and silica which are hard in nature and also due to presence of hard SiC
particles. This is also confirming the result reported by J Babu Rao et al. [11,12].

Fig. 10 shows the tensile specimens before and after fracture. ASTM-E-8 standards were maintained for samples and tested on INSTRON (screw driven) testing machine. The graphical representation of improvement in tensile properties is shown in Fig. 11.

The increase in strength properties with rise in SiC reinforcement has been reported by M.V. Rotti [13]. The increase in strength is not appropriate through subsequent hardness increase with non-uniform stirring times in composite preparation leading to agglomeration. Also, by increasing SiC content the decrease in elongation is found which seems to be relatively visible from the improved hardness associated with increased SiC contents.

The increase in mechanical properties like ultimate tensile strength, yield strength and modulus of elasticity with increase in reinforcement content of alumina and a decrease in ductility have been reported by Khalid et al. [14]. The reasons for enhancement in properties might be ascribed due to the presence of brittle particles which are hard in nature. The enhancement in properties may be attributed due to the presence of hardest ceramic particles fused in A6061alloy. Similar behaviour is reported by Gonzalez et al. [7] and explained the strain hardening effects on increase in load at ductile conditions. Several researchers [15,16] reported that the stress is transferred to the adjacent particles initiating larger particulate cracks leading to final combination in the cavities.

The SEM micrographs of fractured specimens for both alloy and composites are shown in Fig. 12(a–d). From Fig. 12a, a small number of dimples are seen indicating the low plastic deformations during the tensile tests. Also, from Fig. 12c the cracks are identified in the fly ash particle at higher strains indicating that the load has been taken by the fly ash particles by improving the tensile properties. SiC particle pull out is seen from Fig. 12d indicating the cause of fracture.

### 3.5. EBSD analysis

Electron back scattered diffraction (EBSD) images of Al-Zn/Flyash/SiC Composites at different fractions of volume and its effect on average grain size are shown in Fig. 13 respectively. The grains which are coarse are perpendicular to the direction of rolling is seen in the Al-Zn alloy matrix. The grain
size in Al-Zn alloy reinforced with fly ash and SiC particulates are considerably finer than the matrix alloy. The development of fine grains which are equiaxed is the outcome of dynamic recrystallization owed to strong plastic deformation and it is evident that the fly ash particles act as a grain refiner.

4. Conclusions

1. Light weight hybrid metal matrix composites are prepared using vortex method successfully.
2. The fly ash and SiC particulates were mixed in equal weight proportions and reinforced in Al-Zn alloy matrix uniformly.
3. Voids and discontinuities are not seen in the matrix as well as composites and a uniform distribution of fly ash and silicon carbide particles are seen through microstructures.
4. The oxygen peaks and other contaminations were not identified in the matrix and composites due to the utilization of inert gas during the castings.
5. Densities for composites were found decreased when related to the base alloy and this may be attributed due to the low-density levels of the fly ash. The theoretical densities were compared with measured ones.
6. The Vickers hardness number for composites reinforced with fly ash and SiC were found to be increased when compared to the base matrix, the improvement in the hardness may be attributed to the presence of rigid and tough Al_{2}O_{3} and Si present in the fly ash and silicon carbides.
7. With increase in SiC and fly ash reinforcements the ultimate tensile and yield strengths were found increased compared to the base alloy.
8. From EBSD analysis the grain size in Al-Zn alloy reinforced with flyash and SiC particulates are considerably finer than the matrix alloy

Conflicts of interest

The authors declare no conflicts of interest.

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