

Effect of Hot Forging on High Temperature Tribological Properties of Aluminium Composite Reinforced with Agro and Industrial Waste



Mohanta Gopal Krushna, Panda Sasank Shekhar, Senapati Ajit Kumar

ABSTRACT: Objective of the present work focus to study the effect of hot forging on high temperature tribological properties of aluminium composite reinforced with agro and industrial waste, i.e. fly ash and Rice husk ash. The developed MMCs are hot forged at a temp of 450°C with a reduction of 80% in different step. The as cast and forged alloy and its composite are subjected to microstructural analysis and wear test. Microstructural analysis shows uniform distribution of the particulate in the matrix alloy. After forging reinforcement RHA and FA are united towards the material flow direction throughout hot forging. During hot forging, the effect of plastic deformation and high temperature lead to recrystallization of Al6061/RHA and Al6061/FA MMCs with grain refinement. Refinement of grain enhanced the mechanical strength. The worn out surfaces are seen by SEM to know the mechanism of wear. Forged composite possesses lower wear rate under all the condition compared with as cast alloy and composite. Hot forged Al6061 alloy reinforced with fly ash composite gives least wear rate at 150° C in comparison with its room temperature.

Key words: Al MMCs, stir casting, Fly ash, Rice husk ash, Hot Forging, wear properties

I. INTRODUCTION

Metal matrix composites (MMCs) particularly aluminum based composites gaining attraction towards automobile and aerospace industries because of its excellent properties, like high specific strength, low density and good abrasion resistance to wear and tear [1]. Owing to lower thermal coefficient of expansion and tolerable mach inability these materials are gaining popularity over other conventional materials [2]. Recently, researchers are dispensing with costly reinforcement materials such as SiC, Al₂O₃. Normally stir casting route is adopted to manufacture component with aluminium Matrix Composite (AMC) where there is considerable drainage of costly materials i.e. SiC, Al₂O₃. In order to lower the cost of production, addition of cheaper reinforcement such as fly ash, rice husk, coconut shell ash have been chosen[3]. But these materials are weaker during formability because metal matrix composites relate with particle rupture and decohesion of reinforcement. MMC produced by traditional fabrication method gives less ductility due to high brittle reinforcement, porosity and agglomeration [4].

As we know that hot working process like forging, rolling and extrusion of discontinuously reinforced MMCs can improve the interstitial bonding between matrix and reinforcement, particle distribution, breaking of particle agglomeration and reduce the defects of composites [5]. However most of the researcher has given attention towards the development and characterization of composite by primary processing technique, little work has been done on the effect of thermo mechanical process on the properties of composite particularly on hot forging. Amongst the secondary processes available hot forging is the best suitable methods which provide better strength, hardness because during this process plastic deformation will be takes place rapidly. Forging method offers distinct and able to reproduce the engineering components performance [6]. Venkatasiva et.al was studied the hot deformation behavior on the wear properties of Al composite reinforced with Al₂O₃. They have reported that hot forged composite gives an enhanced wear resistance compare to the base alloy [7]. Seo et.al investigates the effect of hot extrusion on mechanical properties of Al/SiCp composites. They have concluded that after forging the particle are distributed uniformly with some increment [8]. Keshavamurthy et al. was discussed the wear properties of Al2024/TiB₂ as cast and hot forged in situ composite. They have found that hot forged matrix alloy and its composite gives better refinement of grains. The cast and forged composite exhibit superior micro hardness, lower wear rate and COF than the unreinforced alloy [9]. Tan et al. investigate the behavior of powder processed and extruded Al-Li alloy based composite reinforced with SiC and found that above 20wt% reinforcement there is a considerable decrease in yield strength and ductility [10].

In the present investigation, Al6061 alloy based metal matrix composite containing up to 12% fly ash [MMC (FA)] and 12% rice husk ash [MMC (RHA)] particulates were successfully synthesized using vortex method. Effect of hot forging on wear properties of waste material reinforced MMCs were investigated. The material developed indigenously at the laboratory is expected to be used in automobile industries for making some component such as break shoes. These materials while in use are subjected to rubbing action where temperature rises to 150°c. In order to see integrity of the material it is thought worth to have comparative study on abrasion behavior at 150°c.

II. EXPERIMENTAL WORK

In present work Al6061alloy is used as matrix, which exhibit good casting properties and strength. The chemical composition is given in (Table-1).

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Two different reinforcement is used in this study are Rice husk ash and Fly ash. The chemical composition of RHA and FA is given in the Table- 2 & 3.

Table-1: Composition of Al-6061 alloy

| Chemical Composition | Al | Cr | Cu | Fe | Mg | Mn | Si | Ti | Zn |
|----------------------|-------------------|-------------------|-------------------|----------------|-----------------|---------------------|----------------|---------------------|---------------------|
| Wt% | 95.8 - 98.6 | 0.04 - 0.35 | 0.15 x -0.4 | Ma x 0.7 | 0.8 - 1.2 | Ma x 0.1 5 | 04 - 0.8 | Ma x 0.1 5 | Ma x 0.2 5 |

Table-2 Chemical Composition of Fly Ash (wt %)

| Chemical Composition | Na ₂ O | CaO | MgO | SiO ₂ | Al ₂ O ₃ | K ₂ O | Fe ₂ O ₃ |
|----------------------|-------------------|------|------|------------------|--------------------------------|------------------|--------------------------------|
| Wt % | 0.10 | 1.24 | 0.58 | 56.43 | 13.54 | 0.59 | 4.97 |

Table-3 Chemical Composition of Rice Husk Ash (wt %)

| Chem. Comp. | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | SO ₃ | K ₂ O | Na ₂ O |
|-------------|------------------|--------------------------------|--------------------------------|------|-------|-----------------|------------------|-------------------|
| Wt% | 97.0 | 1.13 | 0.31 | 0.07 | 0.825 | 0.14 | 0.18 | 0.092 |

The metal ingots are properly cleaned before melting to eliminate surface impurities. An electrical resistance furnace with bottom pouring attachment is used for melting. The melting temperature was kept at 700°C then 1wt% of Mg added to improve the wettability of reinforcement particulate in the liquid. Mechanical stirring is done for mixing the Mg in the melt Al alloy. Before pouring into the melt Rice husk ash and Fly ash are preheated to 650°C. A BN coated stainless steel rotor is rotated at a speed of 600-650 rpm for 10 mins to create a vortex in the melting metal. Then the molten composite transferred into from crucible to a rectangular steel mould. The hot forged cast matrix alloy and its composite are cut with respect to the required dimension. The samples are heated in a furnace to a temperature of 450°C for 3 hrs. Continuous soaking of the sample, followed by hot forging was done with Press forging machine. The deformation was carried out slowly at different stage of forging. The initial thicknesses of strips are 20mm and the working is done in steps i.e. 10% in each step. First the thickness is reduced to 8mm. In between each step, the strips are soaked for half an hour before the forging is resumed. Fig.1 shows the sample dimension of forged composite and cast alloy. Hot forged alloy and its composite were subjected to optical microstructure studies, hardness test and wear. For microstructural study Optical microscope (XJL 17) and Scanning Electron Microscope (SEM-JEOL/EO, JSM-6510) was used. Density was measured by Archimedean principle. Wear test was conducted by using Pin-on-disc set up at room temperature and at 150°C. The sample size has been prepared as per ASTM; 8 mm diameter and 30 mm in length. The weight loss was calculated at constant load, RPM and time. An electric sensor is connected to the PC to get the readings for tangential forces and the Coefficient of Friction (COF).



Fig. 1. Sample Dimension of Forged and as cast composite

III. RESULT AND DISCUSSION

A. Morphology of Rice husk ash and Fly ash

Size and shape of the rice husk ash and Fly ash particles in the powder was observed under SEM and given in fig. 2. The size of the RHA particles vary between 5 to 10 microns and the shapes of particles are irregular and sharp edges. The size of Fly ash is in the ranges of 15 to 25microns and the shapes of the particles are irregular.

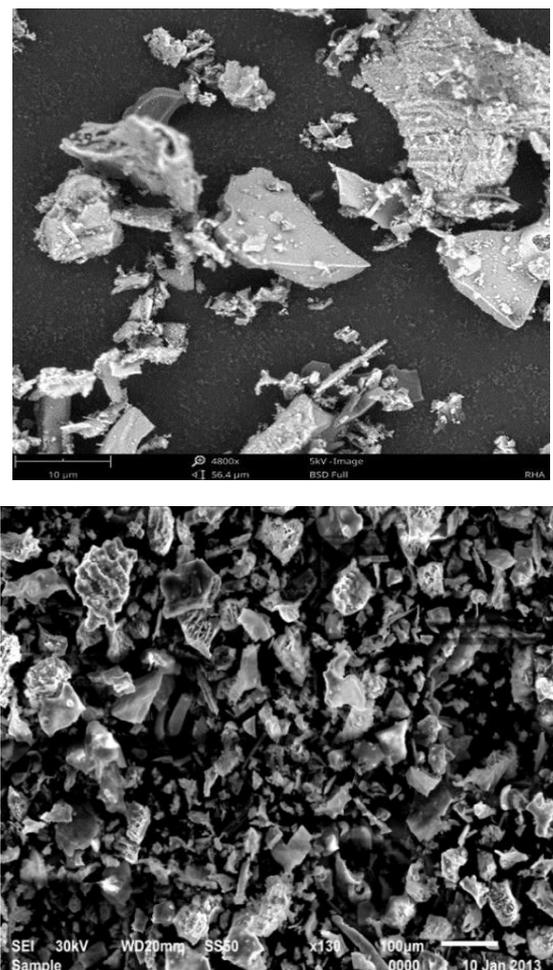
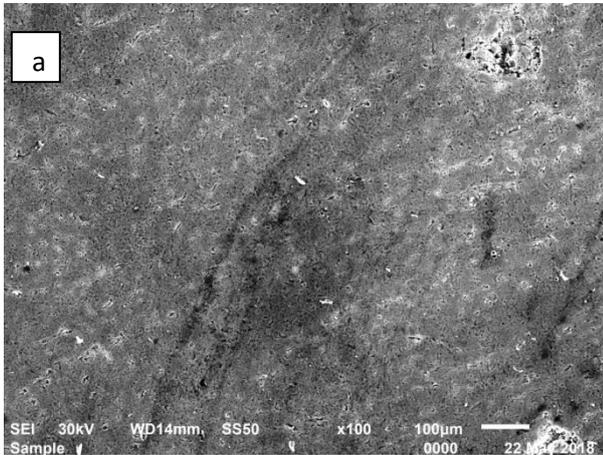


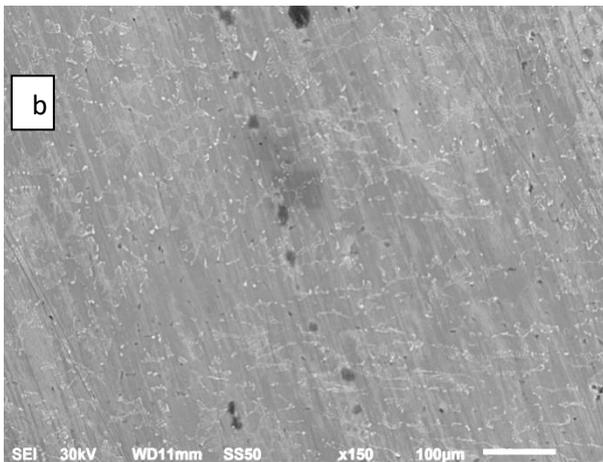
Fig. 2 : SEM micrographs of RHA and FA particles

B. Characterization of cast and forged Composites

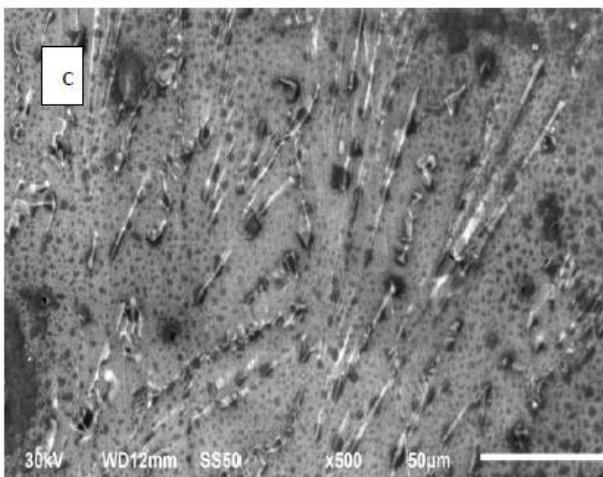
The Scanning Electron and Optical micrographs of both matrix alloy and composite in, as cast and forged condition is shown in the Fig 3. The microstructure clearly indicates that the reinforcement are distributed homogeneously in the matrix alloy.



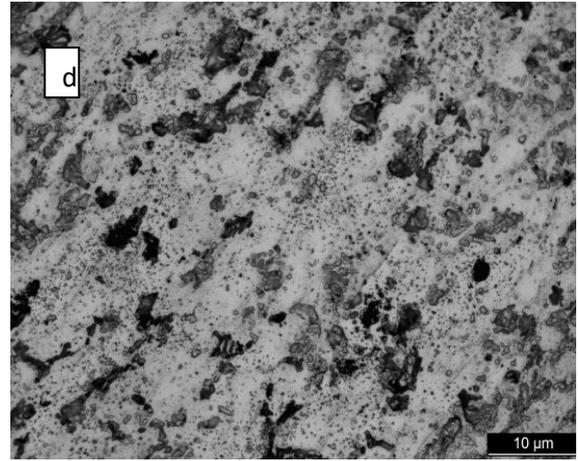
Cast Al6061



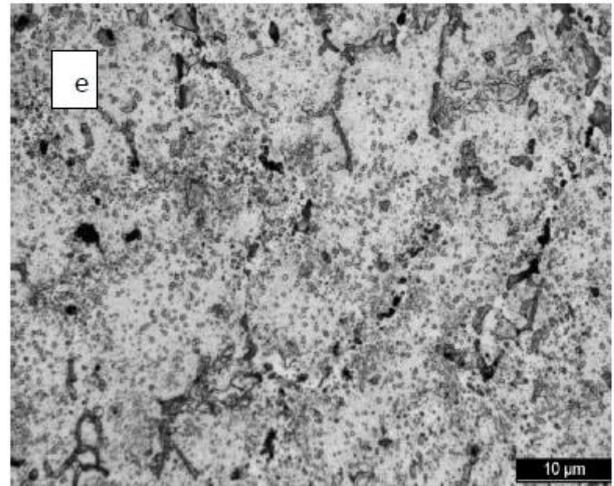
Cast Al6061/RHA



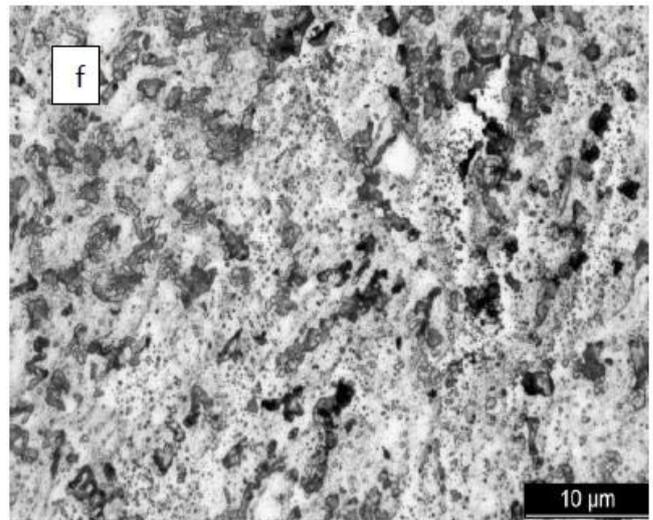
Cast Al6061/FA



Forged Al6061



Forged Al6061/RHA



Forged Al6061/FA

Fig 3. (a-f) SEM and Optical Micrographs of cast and forged Al6061 and its composites

Fig 3. (a) Shows the SEM of as cast Al6061 alloy revealed the presence of dendrite structure caused by solidification. The high cooling rate during solidification forms such dendrite structure. Due to the presence of Mg and Si in a little bit higher in amount in Al-6061 alloy the inter-metallic phase, Mg₂Si formed around the dendrites during casting. Fig (b) shows the image of Al6061/RHA AMC, revealed that RHA particles are distributed uniformly in Al6061 matrix alloy. It also revealed the integrity between Al-6061 and RHA. Fig(c) shows the FA particulates distributed uniformly throughout the base metal matrix. No casting defects were shown, which demonstrates the quality of casting. Uniform distribution of FA particles is essential to obtain higher mechanical properties of MMCs. Fig 3. (d-f) shows the optical micrographs of Al6061 alloy and it's composite in hot forged condition. Form the observation it is cleared that forging lead to reduce the porosity of the cast composites because during hot forging the agglomeration of particulates breaks and bonding between matrix and reinforcement. Reinforcements, i.e. RHA and FA are dispersed in the metal matrix. After deformation due to the transfer of load from matrix to the reinforcement the mechanical bonding between matrix and reinforcement improved in the composite. It is also observed that even after hot forging the particulates are not pullout from the matrix.

C. Density Measurement

Density is the physical property of composite that reflects the characteristics. Table-4 shows the density of three materials as cast Al6061 alloy, RHA composite and Fly ash composite and Fig.4 show the variation of density of the base metal and other two reinforced composite. It was observed that after forging density slightly increased in three materials. This is because of the reduction of porosity in the prepared castings.

Table-4: Density of Alloy and MMCs.

| Material | Cast (Before Forging) (In g/cm3) | After Forging (In g/cm3) | Difference (in %age) |
|--------------|----------------------------------|--------------------------|----------------------|
| Al6061 alloy | 2.611 | 2.713 | 3.9 |
| MMC (RHA) | 2.571 | 2.612 | 1.6 |
| MMC (FA) | 2.376 | 2.478 | 4.3 |

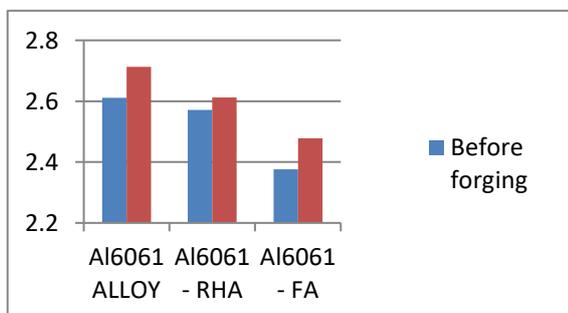


Fig.4: Variation of density before and after forging

IV. WEAR PROPERTIES

Due to the emerge application of AMCs in automobile industries, the specimens are aligned exactly according to the wear testing method on Pin-on-disc set up. The specimens are then tested as per standard procedure. Table-5, 6, 7 & 8 shows the result of wear behavior of the cast and forged Al6061 alloy, AMC with RHA and AMC with fly ash at 150°C and room temperature with constant load and rpm. From the experiment, it was shown that there is a decrement of wear rate in the hot forged composite as compare to as cast composite. Further, among all the composites study it was observed that in both the cases, the FA reinforced composite having less wear rate as compared to the base alloy and RHA reinforced composite. This is due the high bonding between the matrix and FA particulates in the composite. The composites with coarse particles have large interfacial bonding with the aluminium matrix, which avoids particle to pull out of the surface. Due to this the hardness of the composite increases and the wear rate also reduces.

Table. 5: Wear Test Result Of As Cast Sample (at Room Temp) Constant Load, Rpm, Time and Temp

| Material | Initial Weight (in gm) | Final Weight (in gm) | Loss Of Weight (in gm) | Wear Rate= Vol. Loss/SD (mm ³ /m) | Specific Wear Rate (mm ³ /Nm) |
|--------------|------------------------|----------------------|------------------------|----------------------------------------------|------------------------------------------|
| Al6061 Alloy | 3.710 | 3.696 | 0.024 | 0.00613 | 0.20 x10 ⁻³ |
| MMC (RHA) | 3.832 | 3.813 | 0.019 | 0.00460 | 0.15 x10 ⁻³ |
| MMC (FA) | 3.881 | 3.869 | 0.012 | 0.00290 | 0.09 x10 ⁻³ |

Table. 6: Wear Test Result Of As Cast Sample (At 150°C Temp) Constant Load, RPM, Time and Temp

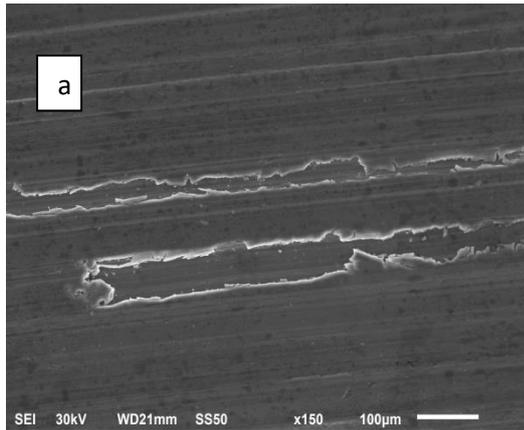
| Material | Initial Weight (in gm) | Final Weight (in gm) | Loss Of Weight (in gm) | Wear Rate= Vol. Loss/SD (mm ³ /m) | Specific Wear Rate (mm ³ /Nm) |
|--------------|------------------------|----------------------|------------------------|----------------------------------------------|------------------------------------------|
| Al6061 Alloy | 3.597 | 3.580 | 0.017 | 0.00436 | 0.14x10 ⁻³ |
| MMC (RHA) | 3.700 | 3.692 | 0.008 | 0.00194 | 0.064x10 ⁻³ |
| MMC (FA) | 3.741 | 3.735 | 0.006 | 0.00145 | 0.048x10 ⁻³ |

Table. 7: Wear Test Result of Forging Sample (Room Temp) Constant Load, RPM, Time and Temp

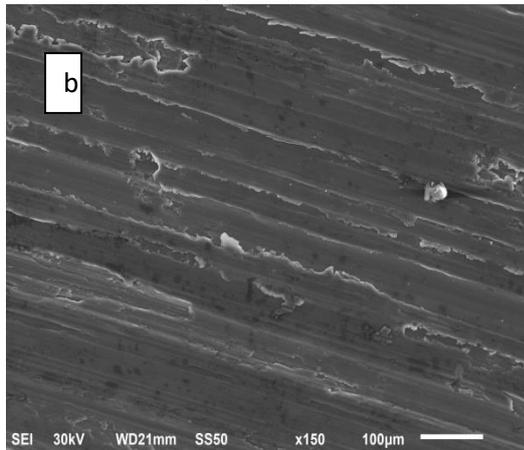
| Material | Initial Weight (in gm) | Final Weight (in gm) | Loss Of Weight (in gm) | Wear Rate= Vol. Loss/SD (mm ³ /m) | Specific Wear Rate (mm ³ /Nm) |
|--------------|------------------------|----------------------|------------------------|----------------------------------------------|------------------------------------------|
| Al6061 alloy | 3.784 | 3.767 | 0.017 | 0.00418 | 0.139 x10 ⁻³ |
| MMC (RHA) | 3.590 | 3.574 | 0.016 | 0.00391 | 0.130 x10 ⁻³ |
| MMC (FA) | 3.732 | 3.719 | 0.011 | 0.00271 | 0.090 x10 ⁻³ |

Table. 8: Wear Test Result of Forging Sample (At 150°C)
Constant Load, RPM, Time and Temp

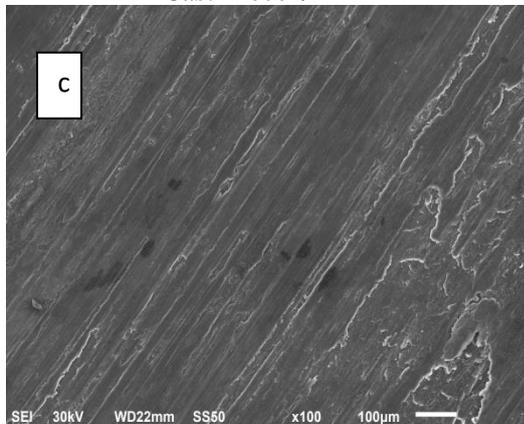
| Material | Initial Weight (in gm) | Final Weight (in gm) | Loss Of Weight (in gm) | Wear Rate= Vol. Loss/SD (mm ³ /m) | Specific Wear Rate (mm ³ /Nm) |
|--------------|------------------------|----------------------|------------------------|----------------------------------------------|------------------------------------------|
| Al6061 Alloy | 3.416 | 3.408 | 0.008 | 0.00196 | 0.065 x10 ⁻³ |
| MMC (RHA) | 3.683 | 3.678 | 0.005 | 0.00122 | 0.040 x10 ⁻³ |
| MMC (FA) | 3.738 | 3.736 | 0.002 | 0.00049 | 0.016 x10 ⁻³ |



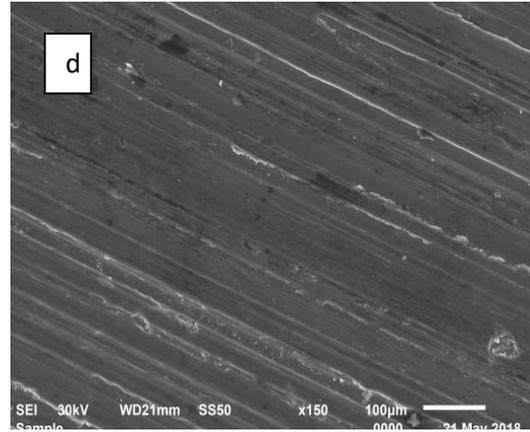
Cast Al6061



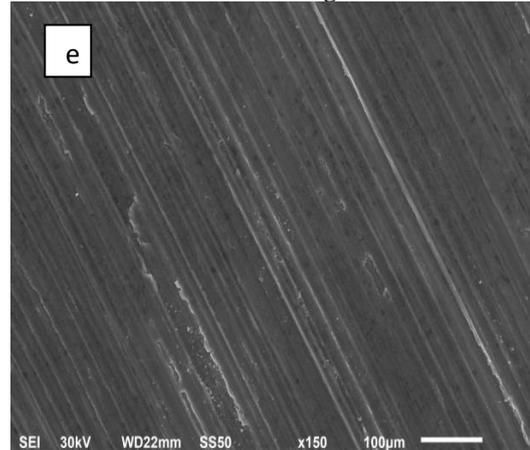
Cast Al6061/RHA



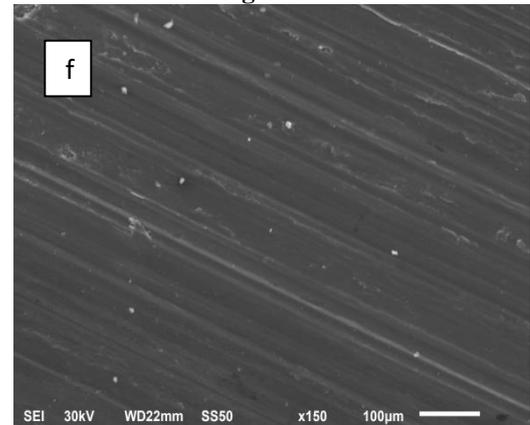
Cast Al6061/FA



Forged Al6061



Forged Al6061/RHA



Forged Al6061/FA

SEM micrographs show the extent of grooving is less in both the matrix alloy and composites on forging Fig. 5 (a-f). Due to which the wear rate of the forged matrix alloy and its composite were lower in comparison to cast alloy, shown in Fig. 5(a). Granular plate like debris particles observed to be present in the grooves. From the above observation it was found that Al6061/FA composites exhibits least wear rate.

IV. CONCLUSION

Form the Present investigation it was concluded that

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- I. The stir casting techniques was successfully adopted for the preparation of as cast Al6061 alloy, Al6016/RHA and Al6061/FA composite. The composites and matrix alloy hot forged by 80% in different step. Hot forging gives better mechanical bonding between matrix and reinforcement compared to as cast composite.
- II. Microstructure reveal that forging did not promote damage on the composite and it also minimizes the porosity of the composite.
- III. Forging improves the mechanical properties without hampering the ductility, this is due to super plastic deformation during forging.
- IV. Wear rate of forged composites lower than that of cast one in all test condition. The forged Al6061/FA composite material had shown least wear rate at 150°C in comparison with its room temperature wear, this is because formation of work hardened layer.



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