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DRY SLIDING WEAR AND FRICTIONAL BEHAVIOUR OF A356 - X WT% SIC/GR HYBRID COMPOSITES PRODUCED BY STIR-CUM-SQUEEZE CASTING METHOD

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Due to poor wear characteristics of aluminium alloy, an attempt is made to produce hybrid metal matrix composites using A356 as matrix material with reinforcements varied wt % about 3, 6, 9,12 respectively of Silicon Carbide (SiC) and constant wt % of Graphite (Gr) through squeeze casting technique. Further the casted metal matrix composites were heat treated based on T6 condition reveals that improve of wear resistance and reduction of coefficient of friction. Using wear testing apparatus the wear rate and the coefficient of friction for the test samples are measured under normal temperature in dry condition by varying load of 10,20,30,40,50N and sliding distance of 1000,2000,3000 m respectively. From the casted test samples, it has been found that the wear rate is maximum for A356 with 9wt% SiC and 3 wt% Gr hybrid composite test sample and coefficient of friction is minimum for the virgin A356 test sample. Eventually wear mechanism was observed through scanning electron microscopy (SEM) on the worn-out surface, displayed dominant adhesive wear with an accumulation of deformed adhesive plates and wear debris collected in the wear pit.

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1. Introduction

Aluminum and its alloy play a vital role in protecting the reinforcement in metal matrix composites because of less effort in manufacturing, including additional exceptional features like reduced density, high elevated hardness, and greater resistance to erosion. [1] Aluminum alloys are categorized into wrought aluminium alloy and alloys of cast aluminium. Based on the principle alloying element, cast aluminium alloys are grouped into nine series. Out of these nine series in cast alloy ofaluminium, the 3xx.x series of castings is a standout amongst the most generally utilized material, on account of high versatility by contents of high silicon non-metal and its involvement to liquidity and heat treatment responses which gives an assortment of high strength alternatives.[2]Because of fast growth, sales and usage of metal matrix composite had made to expand the manufacturing scale every year. Hence, during choosing composite materials, creating manufacturing simple with cost reduction has turned into a top needs [3-4]. It has been noted that even a small amount of hard phase and soft phase ceramic reinforcements in aluminium composites makes considerable progress in its performance in the hybrid composites. [5-6] Conventional alloys as used in the past are compared with aluminium metal matrix composite containing silicon carbide as reinforcement particles. [7-8].This shows greater mechanical strength resistance to material erosion during wear; because of the way that silicon carbide particle has high elastic modulus and high strength at the yield point. On the contrary conventional alloys have very low strength at yield point and high plasticity.[9] An exhaustive survey over the literature works unmistakably exhibits that either a coating type or accumulation of solid lubricants such as Gr,

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MoS_2, etc, drastically improved the resistance to wear of the material.[10] Of all types of solid lubricants available, graphite is utilized by all that showed improved outcome in metal matrix composites among silicon carbide, aluminium oxide and boron carbide as reinforcement[11-12].Among various available casting processes, stir casting is apt for discontinuous metal matrix composites due to its specific application commercially being practiced currently. The refinements of micro and macro structures are obtained due to high pressure. Gas porosities and shrinkage porosities are completely reduced in this process. The material strength is mainly dependent on the particle size of the selected reinforcement. The property is enhanced by smaller grain size. The applied squeeze pressure of 100 to 140 MPa, melting temperature of around 600°C to 700°C and 250°C die temperature are recommended in this process to get feasible results. [13] Wear is a standout amongst the most normally experienced mechanical issues in industries prompting the substitution of parts and congregations in manufacturing. In any case, wear decreases the working productivity by expanding material misfortunes, fuel use and the rate of part substitution.[14] Metal matrix composites subjected to dry sliding wear behavior plays a prime role in areas where the pairing mechanism has correlative motion between two contact surfaces. Piston reciprocating inside the cylinder of the IC engine and disk brake in an automobile are some of the examples of this type. [15] Hard particles as reinforcement in matrix alloy develop their tribological properties; on the contrary results in extreme counter surface wear or deflate the process of material removal.[16-18] When two sliding surfaces are in motion; it is subjected to shear stress beneath the contact area of the material, which leads to permanent deformation in the subsurface region. This plastic deformation is overcome by using graphite as reinforcement which is rich in lubricant film by diminishing the amount of shear stress produced.[18]The observation made on a different combination of aluminium hybrid metal matrix composites are Al-10SiC-6GR, Al-15SiC-3GR or Al-5SiC-5GR shows that decrease in coefficient of friction concurrently minimize the composites wear. The rate of wear reduces with graphite addition at a rate of 5%. Further addition of 10% graphite increases the wear rate again. The hybrid combination Al/5SiC/5Gr gave superior tribological properties, while the increasing amount of graphite above 5% would increment the wear rate. [19-21]The higher hardness influence of silicon carbide over aluminium alloy composite is advantageous though it lacks the machining ability. Graphite particles fulfill this gap to overcome this machining ability to annihilate the wear rate of aluminium silicon carbide composites addition to form Al-SiC-Gr hybrid composite. Block-on-disk tribometer experiment is carried out below dry sliding state at a varying load of 40N, 80N, 120N with disc speeds 0.25, 0.5 and 1m/s. The sliding distances of 150m, 300m, and 1200m is taken to unravel the tribological properties [22].

From the above summary of the literature survey, for this combination of A356-silicon carbide-graphite, both mechanical and tribological properties has been investigated using stir casting, compo-casting, and powder metallurgy, etc. and some of the draw backs encountered are difficult in achieving homogenous distribution of materials, lack of wettability, porosity issue, possibility of reaction between matrix and reinforcement, restricted particle size, fracture across reinforcement, high cost, etc. So far no research work has been carried out using stir cum squeeze casting process for the above combination. Based on the above collective information and to overcome the above drawbacks, the interest aroused to fabricate A356 with *x* (3/6/9) wt% SiC and 3% Gr hybrid composite using stir cum squeeze casting route along with T6 heat treatment to obtain improved mechanical and tribological property to fulfill this gap.

2. Experimental methodology

2.1.Fabrication of Hybrid Composites

Five different sample combinations are casted based on planned parametric conditions using stir cum squeeze casting setup. In A356-SiC-Gr combination, SiC in varying weight percentage of 3,6,9,12 with a fixed weight percentage of graphite as 3 along with virgin A356 to obtain five samples. A356 aluminium alloy is meltedto molten phase in a furnace to obtain a homogenous mixture. Hexachloroethane-C_2Cl_6 have the ability to eliminate impurities and air pockets from the liquid metal and hence 10grams are used in casting as a degasser and pore-free sound casting is obtained after the liquid metal flows into preheated die followed by application of high squeeze pressure, to obtain a sound casting[27].

Additionally for remaining four composite combinations were prepared under the following condition. The two types of reinforcements were taken in two separate pots and preheated to a temperature of 300˚C in-built preheating furnace. Now the preheated reinforcement particles are made to spread over the liquid metal uniformly by a stirrer arrangement agitated at a constant speed of 400 rpm for five minutes for uniform dispersion of matrix and reinforcement. Magnesium plays the role of wettability agent; hence pure magnesium billet with an equal weight percentage of reinforcement is added into the liquid melt. The molten metal's are transferred into the die cavity maintained at 225˚C through the preheated passage to bottom pouring furnace. A pressure of 140Mpa is applied through the punch from hydraulic power press results in squeezing of cast ingots into the die cavity. The split die is opened after a few minutes and cast samples were taken out.

Finally, for T6 heat treatment, a cast samples are dipped into a solution and solution is gradually raised to a temperature of 540˚C for continuous 4 hours. After 4 hours, the samples are taken from the solution and rapidly cooled in the water at 25˚C to prevent phase transformation. Next, quenched samples are subjected to artificial aging at 155˚C for a time span of continuous 4 hours. In the end, the specimen is exposed to cool air until it reaches the room temperature. Then the heat treated specimen was prepared as per ASTM standard procedure for mechanical testing. The test examples are set up according to ASTM measures to assess the hardness and ultimate tensile strength.

The E10 ASTM hardness test of squeeze cast virgin A356 alloy (S1) is 85.1 VHN, stir cum squeeze cast A356 with 3wt%SiC and 3 wt% Gr (S2) is 89.5VHN, A356 with 6wt%SiC and 3 wt% Gr (S3) is 92.5VHN, A356 with 9wt%SiC and 3 wt% Gr (S4) is 96.4VHN respectively. The E8-04 ASTM ultimate tensile strength of squeeze cast virgin A356 alloy is 260 MPa, stir cum squeeze cast A356 with 3wt%SiC and 3 wt% Gr is 290 MPa, A356 with 6wt%SiC and 3 wt% Gr is 310 MPa, A356 with 9wt%SiC and 3 wt% Gr is 335 MPa respectively.

2.2. FESEM and EDS analysis

FESEM microstructural analysis[27] (Fig. 1) indicates that the manufactured HMM composite samples has even scattering of reinforcement particles A356 + SiC + Gr.

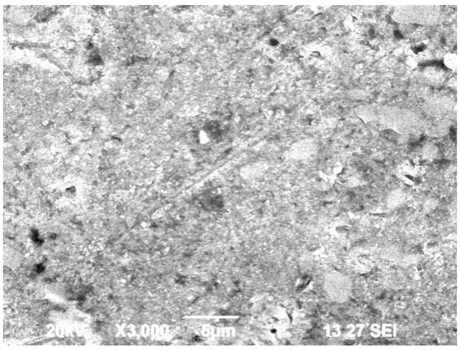


Fig. 1 FESEM micrograph.

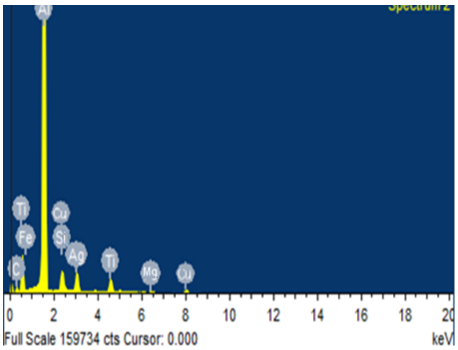


Fig. 2. EDS graph of A356 + SiC + Gr.

It has been analysed from Fig.2 that all the composition displayed Alumnium (Al), copper (Cu), Magnesium (Mg) and iron (Fe) peaksconforming to A356 along with the presence of SiC and C peaks corresponding to SiC in case of A356 + SiC + Gr.

2.3. Tribometer test

Wear test on the dry sliding condition was done as per ASTM G99-05 standard rule for pin-on-disk type tribometer using wear testing apparatus (TR-20LE-M108). The heat treated and machined test samples of size ϕ8 mm and height 30 mm as displayed in Figure 3, is used as pin material to slide over the disc with applied load varied from 10,20,30,40,50 N and varying sliding distance (SL) of 1000 m, 2000 m ,3000m were employed. Likewise other dependent process parameters of sliding speed of 245,490, 735 rpm and run time of 10 minutes, track dia of 130 mm were kept constant. By using organic solvent, the test sample and the counter face are washed thoroughly to eliminate wear traces.Each test sample pin was weighted using the measuring scale having a precision of 0.1mg to measure the loss of wear before and after testing. The tangential load normal load applied was recorded from the strain gauge, by which the coefficient of friction were determined. Each test experiment is repeated 3 times and the mean result was noted.

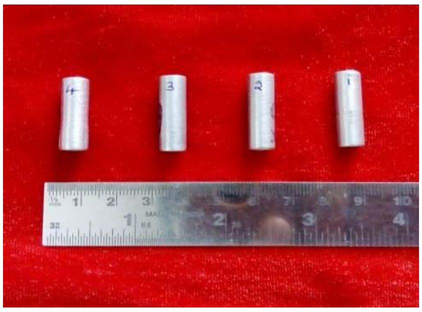


Fig. 3. Tribo meter Test samples.

3. Results and discussion

3.1.Wear rate

A concise depiction of the wear mechanisms based on experimental annotations was observed in different aspects. The combination of four test specimens is subjected to dry sliding with increasing load condition of 10-50N. The hybrid composite of A356 with 9 wt% SiC and 3 wt% Gr test specimen having lower wear rate than other samples because of pouring free tightly bonded higher weight percentage of reinforced particles under applied squeeze pressure was observed. For this combination hardness and strength is greater for the other test samples. It is also experimentally noted that increasing in distance of sliding span from 1000 m to 2000 m increase the rate of wear for all load variants, again increment in a span of sliding from 2000 m to 3000 m for all load variants, the wear rate tends to decrease due to hardening of both the pin and counter disc followed by softening of material was observed in Figs.4a-c.

By the addition of different weight percentage of SiC and Gr using stir cum squeeze casting route, the hard and the soft reinforcement particles showed mild wear debris formation due to better interfacial bonding by Gr which function as a solid lubricant between the pin and the counterpart. Graphite has a self-protective lubricating film and transfers during sliding on the wear surface thereby reducing the shear stresses formation. In this hybrid composite, the extreme wear phenomenon is restricted followed by progress in seizure resistance was ascribed to the friction reduction initiated by heating of surfaces is due to the existence of tribolayer containing graphite and iron oxides.

In addition, The SiC particles have much harder and smaller solidification cells in the A356 matrix function as a load-bearing element in a matrix. Hence from the test results was a higher coefficient of friction, for a higher weight percentage of reinforcement particles is typically harder than monolithic alloy and other hybrid composite specimens containing a lower weight percentage of reinforced particles.

The three body wear mechanism observed during sliding between pin and counter face are abrasion, delamination followed by adhesive wear. Tribolayers, for the most part comprising of a fusion of graphite, iron oxides, and aluminum, was created on hybrid composites surface area. Primarily for the entire specimens, abrasion and delamination wear portrays gentle wear which includes a Mechanically Mixed Layer (MML) or tribolayer that contains iron confined from the counter face along with pieces of reinforcement. It is evident that due to continuous sliding surface got worn out by plastic or permanent deformation in the mild state is noted. On the contrary, no evidence of transfer of aluminium or reinforcement to the counter surface was noticed during this entry study. On continuous sliding of all the test specimens, delimitation and adhesive wear prompts serious wear conditions portrayed by broad plastic deformation at the surface was taken note. Also, aluminium particles got relocated to the counter face and on keen observation, it was found that the wear disc contains pieces of particles from reinforcement. Due to vigorous deformation, dynamic re-crystallization formation takes place as a result worn-out at the subsurface area is noticed. On the other hand, for 3000 m sliding distance along with increment inload from 10 N to 50 N, heat treated A356 test sample together with a hybrid composite sample made to slide over the counter surface and observed decreasing tendency rather than increasing tendency for 2000 m sliding distance and is clearly illustrated in Fig.4d.

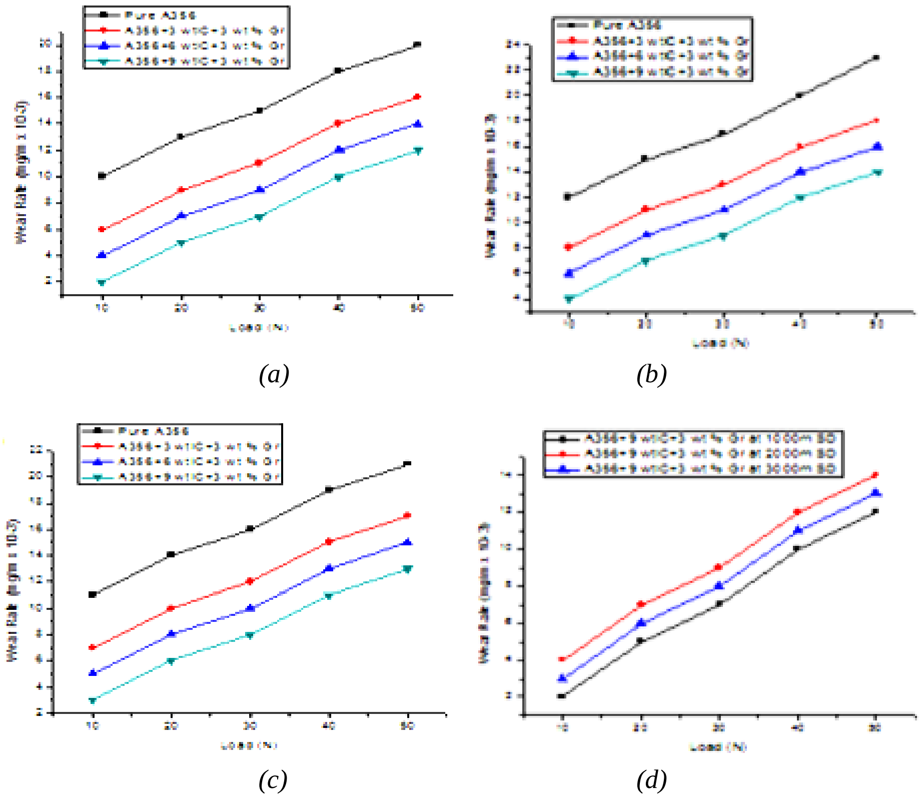
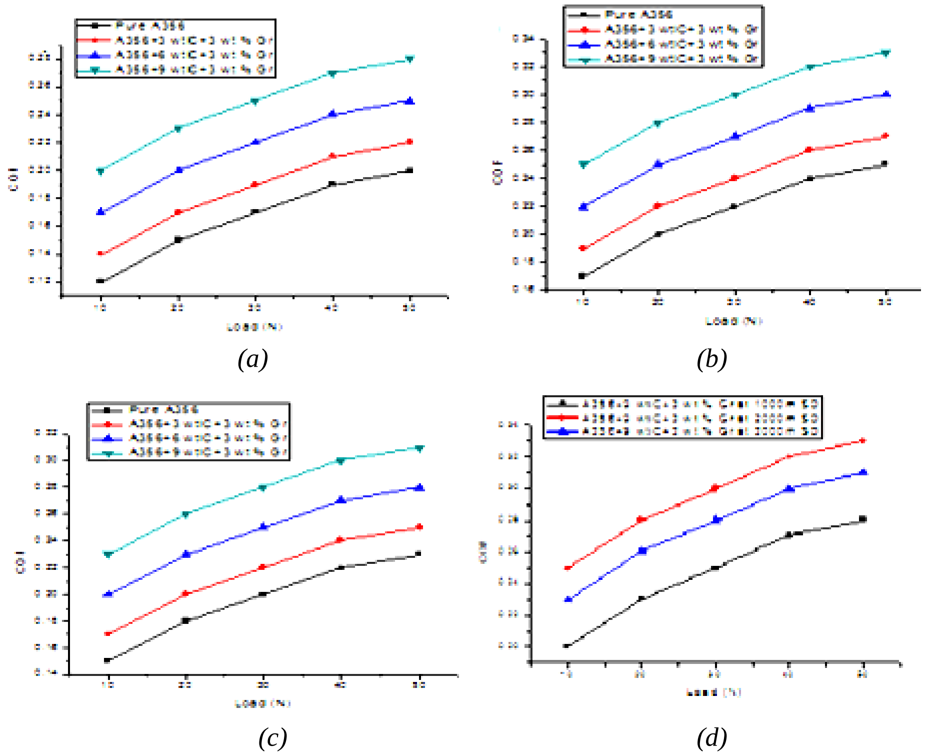


Fig. 4 Wear rate vs Load
a) at 1000m SD b) at 2000m SD c) at 3000m SD d) at 1000-3000m SD.

3.2. Coefficient of friction

Coefficient of friction shows a relationship between two objects subjected to frictional forces and the perpendicular reaction taking place between the object. The friction mechanisms based on experimental interpretation was observed in different outlooks. Figs.5a-c, demonstrates the broad range of coefficient of friction with different loads of 10-50 N at different state of the sliding distance of 1000-3000 m in that order. It is seen that the load applied followed by sliding distance has affected the coefficient of friction for considerable number of materials proposed over for this examination. The different range of coefficient of friction was observed that for steady increment in the value of the coefficient of friction with an increment in load applied from 10-50 N and sliding span of 1000 m to 2000 m and diminishes marginally for 3000 m than 2000m sliding span condition for higher coefficient of friction. Conversely, based on examination of all loads, the coefficient of friction of A356 with 9 wt% SiC and 3 wt% Gr hybrids composite is higher when compared with other specimens because of higher strength leads to the severity of plastic deformation for the test samples. all the test samples inspected there is a The rise in coefficient of friction with increment in connected loads from 10 to50 N and sliding span of 1000 m to 2000 m, can be credited to the way that, builds the contact of SiC particles to the counter surface and furthermore the exchange of particles from the aluminum matrix to the counter surface.

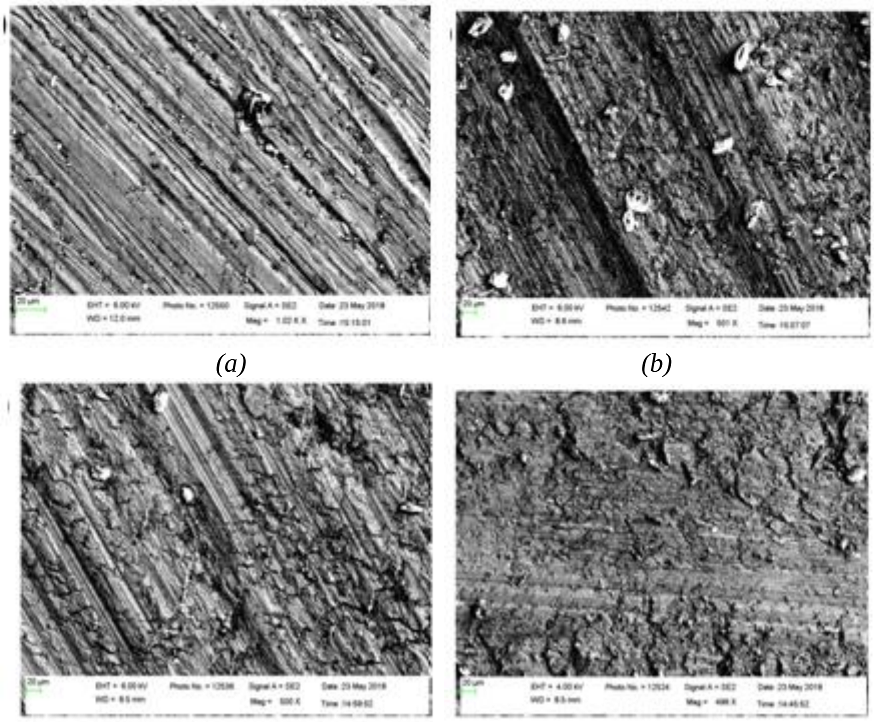


Figs. 5 COF vs Load
a) at 1000m SD b) at 2000m SD c) at 3000m SD d) at 1000-3000m SD.

These are potential purposes behind the expansion in the coefficient of friction with the increment in load at 50N. Additionally, the SiC reinforcement in the hybrid composites are squashed out into the mating surfaces creating mechanically mixed layer and the smudge graphite particles made the lubricating film in the contact surfaces. Between the contact surface, the produced lubricating oil film last for a shorter span 1000 m sliding distance This film vanishes from the contact surface after the expansion in sliding distance from 1000 m to 2000 m and they are gets dissipated from the contact surface because of delayed sliding brought about rise in temperature. This brings about an increased coefficient of friction with an increase in the sliding distance up to 2000 m. Increasing the sliding distance by 3000 m give rise to continuous friction results in material softening takes place continued by the formation of tribolayer film and it is clearly indicating in Fig. 6d.However, for the entire test interval examined, virgin alloys and lower weight percentage of hybrid composite manifest the lowest coefficient of friction while stir cum squeeze cast hybrid composite with T6 heat treated for A356 with 9 wt% SiC and 3 wt% Gr recorded highest values of coefficient of friction.Through the process of solidification, relocation of particles is affected by three mechanisms namely agglomeration, sedimentation and rejection of particles have been investigated to solve this problem. To overcome this stir cum squeeze casting technique produce pore-free equal distribution better interfacial bonded sound castings having better strength was obtained. Also, the hard nature of SiC particles plays higher hardness and strength while the soft nature of Gr particles in the matrix showed outstanding anti-friction behavior and possessed the highest coefficient of friction.

3.3. Scanning Electron Microscope Analysis

The SEM micro graph investigation is performed on the wear surface to find out the mechanism of wear by stir cum squeeze cast A356 with 9 wt% SiC and 3 wt% Gr composite tested sample taken after wear test. Worn surfaces of the composite showed various appearances for different loads and sliding conditions. Remarkable smearing caused by deep-continuous grooves and a little amount of material flowing plastically is also observed at 10 N and 50 N respectively. Adhesive wear is more dominant containing plates of distorted adhesive materials. Along with this wear type, wear debris is also produced by fracture formation accumulated over the pit formed by adhesive wear and it was clearly represented in Figs.6a-bsamples at 10 N, b) 5 N load, c) 1000 SD d) 3000m SD.



(a) *(b)* *(c)* *(d)*

Figs. 6 Worn surface for S4 Test a) at 10 N, b) at 5 N load, c) at 1000 SD d) at 3000m SD.

Deep continuous grooves and wear debris were wide spread on the track of counter surface are highlighted after sliding took place. Transfer of material from the pin to the disc surface is obviously observed at the low sliding condition of 1000 m. Coefficient of friction gradually reduces due to continuous friction between mating surface causing softening of the material took place along with the formation of tribo-oxide film and it was clearly indicating in Figs.6c-d.

4. Conclusions

From the observation made for four test samples to study the tribological behaviorof A356 and A356 with *x* (3/6/9) wt% SiC and 3 wt% Gr hybrid composites processed by stir cum squeeze casting technique with T6 heat treated condition, the inferences are highlighted and are listed below.

Stir-cum-squeeze cast virgin A356 and A356 with *x* (3/6/9) wt% SiC and 3% Gr aluminium hybrid metal matrix composites with T6 heat treated four test samples showed outstanding mechanical and tribological property due to strong bonding between matrix and reinforcement make it a homogeneous mixture.

Couple the effect of increment in a weight proportion of SiC particles in the melt with applied high squeeze pressure showed an increase in hardness and ultimate tensile strength were noticed.

In behalf of all test sample conditions, wear rate intensify with all load conditions from 10 N to 50 N. Wear rate also intensify with an increment in the sliding distance for 1000 m and 2000 m. Further, the wear rate reduces with an increment in sliding distance from 2000 m to 3000 m. because hardening of both the pin and counter disc takes place leading to softening of the material was observed. From this observation, it is understood that wear rate is highest for the virgin A356 test sample and lowest for the hybrid composite A356 with 9 wt% of SiC and 3 wt % Gr.

For all the test conditions, Coefficient of friction rise for all load conditions for 10 N to 50 N. Coefficient of friction increases for sliding distances 1000 m, 2000 m. Further, it decreases for 3000 m because due to continuous sliding, particles from the pin gets pulled out deposited on the counter surface. From this observation, it is understood that the coefficient of friction is highest for aluminium hybrid composite test sample of A356 with 9 wt% SiC and 3 wt% Gr and lowest for the virgin A356 test sample.

From collective observation made from wear and friction coefficient analysis, it is predicted that wear is abrasion continued by adhesive wear for all load conditions. Minimum wear rate along with improved wear resistance and maximum coefficient of friction is owing to the existence of SiC hard phase particles and Gr soft phase particles. The minimum wear is also due to the formation of tribolayer formed between the pin and the contact surface released by self-lubricating Gr.

The SEM micrograph examination of the surface subjected to wear is implemented for hybrid test sample A356 with 9 wt% SiC and 3 wt% Gr. The consequence of sliding distance has a considerable fractional influence on all the test samples. At higher load particle seizure takes place. The wear mechanism displayed dominant adhesive wear with an accumulation of deformed adhesive plates and wear debris collected in the wear pit.

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