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RESEARCH

Experimental Investigations on Tribological Behaviour of Alumina Added Acrylonitrile Butadiene Styrene (ABS) Composites

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ABSTRACT

Composite materials are multifunctional in nature, which can be custom-made based on the nature of the applications. The challenge of composite materials lie on complementing the properties of one another i.e. materials which go in the making of composites strengthen each other by inhibiting their weaknesses. Polymers are one of the widely used materials which serve a wide spectrum of engineering needs. In the present work, the tribological behaviour of a composite containing Acrylonitrile Butadiene Styrene (ABS) and traces of Alumina is experimentally investigated. Alumina is added to ABS in various percentages such as 1%, and 3% by weight in order to improve the wear resistance of the polymer. Central Composite Design was used to design the experiments and a standard Pin-On-Disk apparatus was used to conduct the experiments. It is observed from the test results that the addition of alumina significantly enhances the wear behavior of the polymer. However, adding more percentage of alumina has led to adverse effect on wear resistance of polymer materials. Abrasive wear mechanism is found to be predominant in the case of alumina added composite materials. It is also found that 1% alumina added composite exhibits excellent wear properties compared to other materials.

1. INTRODUCTION

Specially engineered composite materials exhibit exciting prospects that one may tailor the material based on the application where it is going to be used. This gives an opportunity to overcome the difficulties in the existing materials and replace them with composite materials in order that they give better results and a longer service period. Composite materials also provide an excellent durability and range of working temperatures due to their resistance to high-temperature, corrosion, oxidation and wear. The objective of manufacturing new composite materials is to improve mechanical properties like strength, stiffness, toughness and high temperature performance. In general, the mechanical properties of polymers are inadequate for many structural purposes. Few of the advantages of using composites are that one can reduce the weight significantly, lower vibration transmission, improved torsional stiffness, fire-retardancy, improved gloss-appearance and provide good strength-to-weight ratio. Wear plays a vital role in determining the life period of products which are used as machine elements. Study on tribological behaviour of composites is relatively important in industrial applications. Wear is a removal of material from its surface due to the relative motion with another material. Wear may also include change in dimension due to plastic deformation.

David et al. [1] have reported that the tribological behaviour of material is depended on the processing parameters of the material. They have also reported that the wear characteristics of nano composites depend on important system parameters such as particle dispersion, bulk mechanical properties, waste morphology and transfer layer adhesion morphology, composition and chemistry. Load and speed have also been specified as two important working parameters which influence the wear. Kurahatti et al. [2] have studied the composite materials having high strength and toughness and their work provides examples of the actual and potential uses of nano composite materials in defense. Basavarajappa and Chandramohan [3] have investigated the sliding wear at various loads, speeds and sliding distances. The investigation reveals that graphite composite is having superior wear characteristics than that of the matrix alloy and SiC_p reinforced composite and the wear rate increases with increasing load and decreases with increasing speed up to 4.6 m/s. Anton et al. [4] have studied the friction and wear behavior of sintered manganese–nickel steels by Pin-on-disk tests. The wear of each material and the pin are evaluated from the mass loss and is also converted into the corresponding volume loss of the materials. The wear mechanism observed in all the samples is adhesion–abrasion.

Jin and Hua [5] have highlighted the impact of adding Potassium Titanate Whiskers (PTWs) to Ni-P composites in their investigation. They have reported that PTWs has an outstanding friction and wear properties as well as self-lubrication. The favorable effects of PTWs on the tribological properties of Ni-P-PTWs composites are found to attribute the great strength of PTWs and could be used as a reticulation structure of composite coatings. Raju et al. [6] have found that addition of nano-ZnO particles in polyester changes the microstructure of polyester and prevents the destruction of polyester banded structure during the friction process, which might be one of the anti-wear mechanisms of nano-ZnO. It is observed from the investigation carried out by Brostow et al. [7] that the pure low density polyethylene (LDPE) has higher frictional properties than the blends of 1, 5, 10, 20 and 25 weight% of melamine-formaldehyde resin (MFR) with LDPE.

Sulima et al. [8] have studied the influence of reinforcing particles on mechanical, tribological properties and microstructure of the steel-TiB_2 composites and have mentioned that the composites are exhibiting higher Young's modulus, Vickers hardness and compression strength compared to the conventional austenitic AISI316L stainless steel. The addition of nano fillers in polymer matrices has significantly improved the mechanical and tribological behavior of polymer based composites [9]. Kumar et al. [10] have studied the tribological behavior of ABS thermoplastic composite added with alumina nano particles and found that the addition of alumina nano particles has apparently reduced the coefficient of friction, mass loss and wear rate of ABS alumina nano composites. The investigations on mechanical and tribological properties of carbon fabric/phenolic composites with different weave filament counts carried out by Wenbin et al. [11] reveals that the adhesive wear mechanism is observed at the initial stage of wear and is transferred to abrasive at the final stage of wear. Sun et al. [12] have evaluated the tribological properties of carbon fabric reinforced composite by studying the effect of heavy load on coefficient of friction, wear volume and temperature rise of composite.

Peipei et al. [13] have investigated solvent free graphene oxide nanoribbons colloids as filler material for epoxy based matrix composites and found that the combination has provided an efficient route to enhance the wear properties and decrease the coefficient of friction for resin-based composites. Ibrahim [14] has investigated the tribological effect on the coefficient of friction and wear rate of polyester composites reinforced by agricultural wastes. They have found a significant enhancement on wear resistance of epoxy composite due to the reinforcement of fibers (carbon and glass fibers, solid lubricants and SiO_2 nano particles) under water lubrication conditions [15]. Walczak et al. [16] have carried out a ball on disc wear test on F3S.20S aluminium composite material and found that SiC reinforced composite has lower wear rate compared to matrix material and observed that the adhesive and abrasive wear mechanism is predominant in wear. The surface morphology of talc added polyurethane composite is observed smoother than that of pure polyurethane under the various load and sliding speed conditions [17]. Ramesh and Suresha [18] have investigated the tribological behavior of carbon epoxy hybrid composite in order to identify the factors which are in effecting the wear properties of the composite. They have found that the parameters such as filler loading, grit size and filler type are the most significant factors in controlling the specific wear rate and have also found the optimum parameters for minimum specific wear rate, coefficient of friction and high hardness for the composite material.

Apasi et al. [19] have studied the wear behaviour of Aluminium alloy reinforced with coconut shell ash particles and have reported that the reinforcement in Al-Si-Fe alloy matrix increases the wear resistive behaviour of the material fabricated by stir casting process. Babic et al. [20] have investigated the tribological properties of A356/10SiC/1Gr hybrid composite with lubrication. It is reported that the wear rate of the composite is about o.5 times lesser than that of the base material. Radhika and Raghu [21] have studied the wear behaviour of LM13 Al/B_4C metal matrix composites synthesized by liquid metallurgy technique and have found that the wear rate is drastically reduced in the case of reinforced composite materials. Charoo and Wani [22] have conducted tribological tests with SAE 20W40 + IF-MoS_2 on a four ball wear testing machine at different operating parameters to ensure the influence of nano-additive on friction and wear of cylinder liner and piston ring tribo-pair. They have found that the addition of nano-additive with lubricant reduces the wear loss by 65 %.

ABS composite is one of the important composites used widely in the present industrial applications namely making of safety helmets, automobile body & fittings, instrument clusters and radiator grills etc. ABS is a non-choice of other materials in the field of automotive interior applications, food containers, luggage shells, household equipments such as vacuum cleaners and hair driers, vacuum formed refrigerator liners, internal trays for refrigerators, telephone handsets. Further ABS is also used in making pipes carrying fluids which causes wear. It becomes necessary to investigate the tribological behaviour of ABS composite and also to find the attributes to enhance the wear resistance of composites. In this context, the present work is focused to investigate wear behavior of ABS with various proportions of alumina under different load/speed conditions.

2. MATERIALS AND METHOD

ABS (Acrylonitrile Butadiene Styrene) is one of the commonly used thermoplastics prepared by cross-polymerization of Styrene and Acrylonitrile with Poly-Butadiene. ABS provides excellent mechanical properties like impact resistance and toughness. Alumina or Aluminum oxide (Al_2O_3) which is a white, colorless crystalline substance is used as an abrasive and refractory agent in polymer due to its higher hardness and high melting point. In the present work, the standard specimens of size Ø6×60 mm made out of ABS with 1 % and 3 % alumina and pure ABS were used to investigate the tribological behaviour of ABS and influence of alumina addition on wear characteristics of ABS. The test specimens of the composites are shown in Fig. 1.

Fig. 1. Test specimens of the composites.

The dry sliding wear test was conducted using Pin-on-disk tribometer against EN31 disc (HRC 40) counter face material. The wear tests were conducted by varying the test parameters such as load, speed/sliding distance and the test duration was kept constant (20 min). The mass loss of the specimen was evaluated by measuring the weight of specimen before and after the wear test. The three decimal accuracy Shimadzhu weighing balance (Made in Japan) was used to measure the mass of the specimen precisely. The frictional coefficient of the wear test was obtained from the computer system interfaced with the tribometer. The standard ASTMG99 was adopted for conducting wear experiment. The wear morphology of the specimen was captured using KYOWA, ME-LUX2, microscope fitted with CCD camera. The captured wear pattern images of the specimens were corroborated with tribological behaviour of the composites.

Table 1. Central Composite Design matrix for conducting experiments.

Run order	Type	Load (N)	Sliding speed (m/s)
1	Factorial	24.4	0.723
2	Factorial	45.6	0.723
3	Factorial	24.4	1.789
4	Factorial	45.6	1.789
5	Axial	20	1.256
6	Axial	50	1.256
7	Axial	35	0.502
8	Axial	35	2.010
9	Centre	35	1.256
10	Centre	35	1.256
11	Centre	35	1.256
12	Centre	35	1.256
13	Centre	35	1.256

Response Surface Methodology (RSM) was used to design the experiment and analyze the results. The objective of RSM is to make use of a sequence of designed experiments to obtain an optimal response. The Central Composite Design which contains 4 axial, 4 factorial and 5 central points, was employed to design the plan of experiments. The experiments were conducted as per the test plan provided by the Design Expert (DE) software. The range of sliding speed of 0.5 – 2 m/s and load of 20 – 50 N were used for designing the experiments by central composite design and the design matrix used for the experimental work is given in Table 1.

3. RESULTS AND DISCUSSION

The dry sliding wear tests were conducted using pin-on-disc tribometer according to the standard on the prepared specimens of pure ABS, 1 % added ABS and 3 % added ABS respectively. The mass loss (ML) of wear tested specimen was determined by measuring the weight of the specimen before and after the tests. The coefficient of friction (COF) for the wear test was evaluated from the computer software interfaced with the tribometer. The input parameters of experimental tests and response parameters (mass loss and coefficient of friction) of experimental results of ABS composites considered for the research work are illustrated in Table 2 as per the design matrix shown in Table 1 for ABS pure, ABS with 1 % Alumina and ABS with 3 % Alumina respectively.

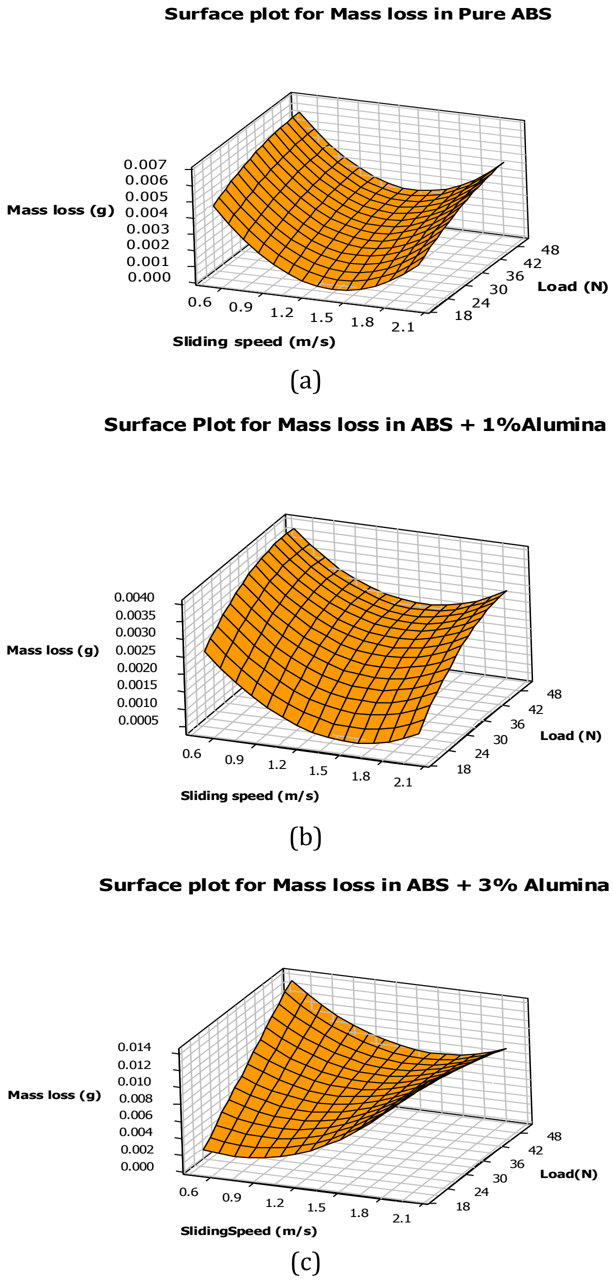
Table 2. Experimental results of ABS composites.

Run order	Response					
	ABS Pure		ABS with 1 % Alumina		ABS with 3 % Alumina	
	ML	COF	ML	COF	ML	COF
1	0.0032	0.333	0.0002	0.352	0.004	0.322
2	0.0039	0.237	0.0023	0.190	0.0085	0.387
3	0.0008	0.259	0.0025	0.314	0.0107	0.299
4	0.0018	0.192	0.0032	0.258	0.0076	0.176
5	0.0006	0.185	0.0013	0.346	0.0019	0.307
6	0.0034	0.195	0.0025	0.284	0.0091	0.239
7	0.0058	0.351	0.0014	0.242	0.0087	0.438
8	0.0053	0.257	0.0033	0.262	0.0100	0.189
9	0.0035	0.301	0.0010	0.287	0.0038	0.235
10	0.0020	0.239	0.0004	0.237	0.0120	0.244
11	0.0012	0.239	0.0006	0.206	0.0071	0.238
12	0.0011	0.223	0.003	0.252	0.0032	0.226
13	0.0009	0.238	0.0016	0.255	0.0028	0.237

3.1 Mass loss characteristics of ABS-Alumina composites

The mass loss behaviour of pure ABS and ABS-alumina composites at various loads and sliding speeds are shown in Fig. 2.

Fig. 2(a) shows the mass loss behaviour of pure ABS. It is observed from the plot that the mass loss is decreasing with increasing sliding speed upto a particular threshold value and is increasing towards the higher values of the sliding speed. It is found that the least mass loss has occurred at the sliding speed 1.5m/s and load 20N. The debris formed at the initial stage of wear occupies the interstitial spaces of contact surface, which could reduce the further wear of material. On the other hand, the wear loss is found to be increased at the higher sliding speed irrespective of the load. The higher heat generation due to wear at the higher speed tends to delaminate the adhered particles, that is why the wear rate is increasing at the second stage of wear. It may be concluded that there are two kinds of wear mechanism predominant in the case of ABS material. The adhesive wear mechanism is dominant at the initial stage of wear and the delaminative wear is found to be dominant during the second stage of wear.



(a)

(b)

(c)

Fig. 2. Response surface plot of mass loss behaviour of composites, (a) Pure ABS, (b) ABS with 1 % Alumina, (c) ABS with 3 % Alumina.

The highest mass loss is observed at the highest load and the least sliding speed. The mass loss is found in the range of 0.0008 to 0.0058 g for pure ABS composite.

The mass loss behaviour of 1 % alumina added ABS composite is illustrated in Fig. 2(b). The mass loss behaviour trend is observed similar to pure ABS material. The mass loss behaviour is exhibited in two stages with respect to sliding speed. In the first stage, the mass loss is decreasing with increasing the sliding speed upto 1.5 m/s, and then the mass loss is increasing towards the higher values of sliding speed irrespective of the load. The composite exhibits increasing trend of mass loss for axial loads.

In general, the mass loss is appreciably higher at the initial stage of wear. The mass loss is decreasing with increasing the sliding speed upto a particular threshold value, then increasing with the sliding speed. The contact surface has more interstitial spaces. The debris formed during the initial stage of wear occupies the vacant or interstitial spaces which lead to reduce the wear rate on the surface. However, at the higher sliding speed the alumina particle would have removed from the contact surface and might have led to abrasive wear on the surface. However the rate of mass loss is observed to be lower compared to the pure ABS material. The mass loss of the 1 % alumina addition is found to enhance the wear resistive property of the composite material. It could be concluded from the wear trend that the adhesive and abrasive wear mechanism are found to be dominative during first and second stages of wear respectively. Though, the mass loss behaviour of the 1 % alumina added ABS composite is found similar to that of pure ABS, the range of mass loss is lower (0.0002 to 0.0033 g) in the wear tests.

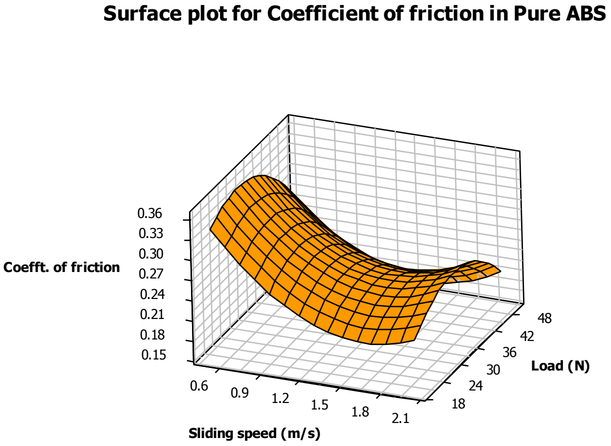
Fig. 2(c) shows the mass loss behaviour of 3 % added ABS composite. It is observed from the plot that the mass loss is higher than that of ABS+1% alumina composite. The increasing trend of mass loss is observed for the lowest sliding speed irrespective of the loads and lowest load irrespective of the sliding speeds. At the highest sliding speed and any load conditions, the mass loss is found to be unvaried. However, the maximum mass loss has occurred at the highest load and the lowest speed conditions. The mass loss varies from 0.0019 to 0.0107g for ABS with 3 % Alumina. Though the alumina content is increased, the mass loss of the 3 % alumina added ABS composite is found to increase due to agglomeration of alumina in the composite material. The agglomeration formed in the material is found to be easily detachable from the surface, which in turn promotes anti-wear resistive property of the material. Moreover, the agglomeration of alumina particles due to the higher concentration results in abrasion of wear contact surface, which could further increase the wear rate invariably in the composite.

3.2 Coefficient of friction characteristics of ABS pure and ABS Alumina composite

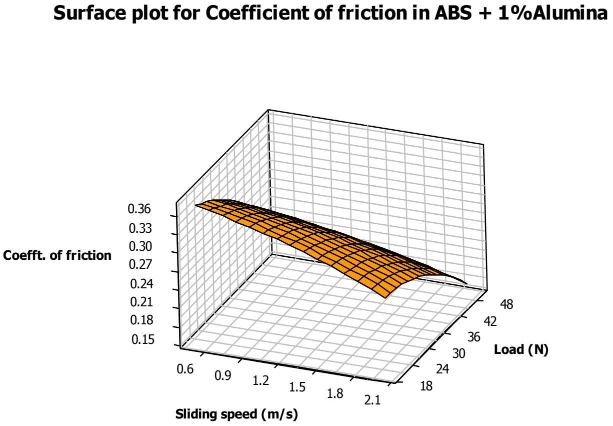
The frictional characteristics of pure ABS and alumina added ABS composite material is illustrated in Fig. 3. The frictional behaviour of pure ABS is shown in Fig. 3(a). The coefficient of friction at the initial stage of wear is higher with respect to the sliding speed. It declines down upto 1.5 m/s of sliding velocity and then it increases towards the higher sliding velocity. In contrast, the frictional coefficient trend is higher at the lower load condition and then raises upto a particular threshold value, and then it declines towards the higher load. The maximum frictional force exhibited by the composite is at the lowest sliding speed and moderate load conditions. The combined adhesive and delaminative wear mechanism is found in the case of pure ABS material.

The frictional behaviour of 1 % alumina added ABS is depicted in Fig. 3(b). The decreasing trend with respect to sliding velocity and load is observed for the composite. The highest frictional force is observed at the lowest values of the sliding speed and load. The combined mode of adhesive and abrasive wear mechanisms is responsible for the frictional force trends in the case of 1 % added ABS composite material.

Fig. 3(c) shows the frictional characteristics of 3 % added ABS composite. The decreasing trend is observed with respect to load. There is no much variation in values with respect to the sliding velocity. The highest frictional force is exhibited by the composite at the lowest sliding speed and the highest load parameters. As the composite material is subjected to the higher mass loss compared to the 1 % added ABS composite, the abrasive wear mechanism is found to be predominant for the entire range of parameters.


Surface plot for Coefficient of friction in Pure ABS

(a)


Surface plot for Coefficient of friction in ABS + 1%Alumina

(b)


Surface plot for Coefficient of friction in ABS + 3% Alumina

(c)

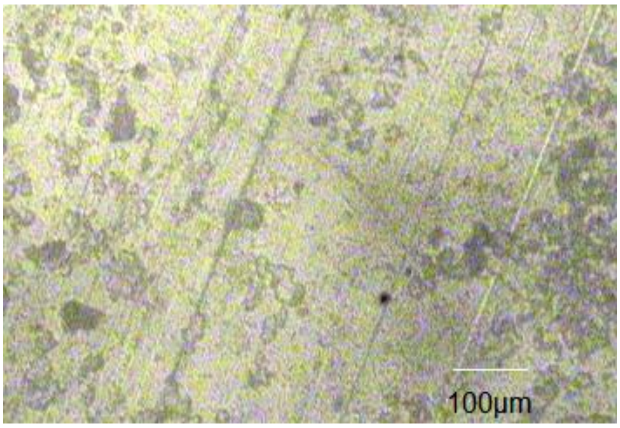
Fig. 3. Response surface plots of ABS pure and ABS Alumina for coefficient of friction: (a) Pure ABS, (b) ABS with 1 % Alumina, and (c) ABS with 3 % Alumina.

As ABS+1% alumina has excellent wear resistive property, automobile parts which require high strength shall be replaced using composite.

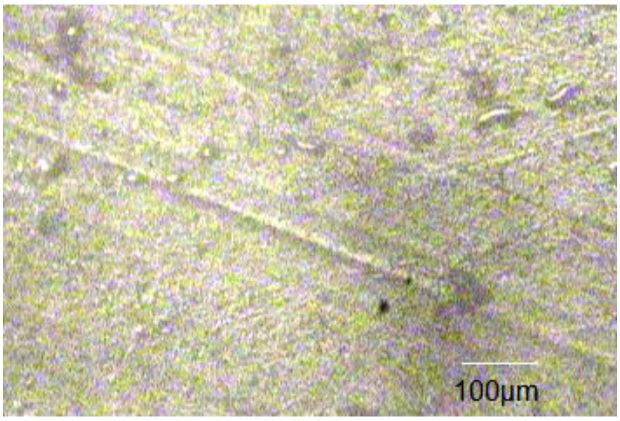
3.3 Optical micro images of wear worn out surface of composite materials

The surface morphology after the wear tests of pure ABS and ABS + Alumina are illustrated in Fig. 4. Fig. 4(a) shows the optical micro image of wear pattern of pure ABS material. It is observed from the image that the material has under gone uniform wear and deep wear track is observed at some places. It is understood from the wear pattern that the material is subjected to maximum wear and more over as the material is soft in nature, it exhibits uniform wear over the entire contact surface.

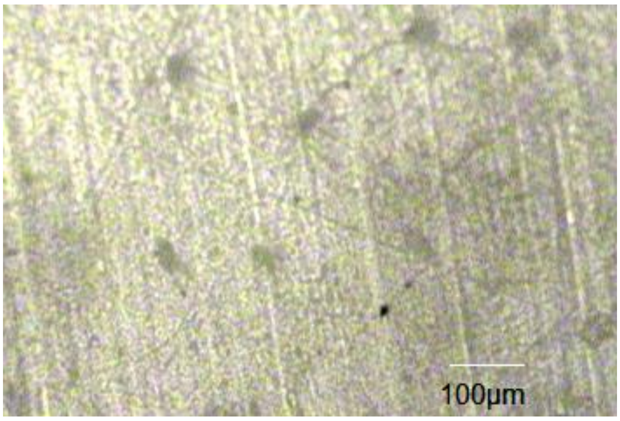
The wear surface morphology of 1 % alumina added ABS composite material is shown in Fig. 4(b). Addition of alumina to the ABS produces micro hard phases in the material, which leads to enhance the pro wear resistive property of the composite material. The dispersed alumina particles are observed in the images. The wear track is also seen in some places. However, the depth of wear track is not to that extent of pure ABS material.



(a)



(b)



(c)

Fig. 4. Wear pattern of (a) Pure ABS, (b) ABS with 1 % Alumina and (c) ABS with 3 % Alumina.

The optical image of worn out surface of 3 % alumina added ABS composite material is depicted in Fig. 4(c). The agglomeration of alumina particles due to the higher percentage is observed in the image. Though the material is containing more percentage of alumina, the integrity of particles with the base material is getting reduced due to agglomeration. Because of this, the wear resistive property of 3% alumina added ABS is appreciably reduced. Shallow type wear track is noticed over the entire contact surface of the material, which proclaims the higher wear rate compared to the 1 % added alumina composite material.

4. CONCLUSION

Based on the investigations carried out on the wear characteristic of pure ABS and alumina added ABS composites at various load and sliding speed conditions, the following salient points could be arrived.

- Addition of alumina to the ABS composite material has significant role on wear property of the material compared to the pure ABS material.
- ABS with 1 % alumina addition has shown better wear resistance characteristic compared to the pure ABS and 3 % alumina added ABS.
- The mass loss of the 3 % added ABS composite is found to increase due to agglomeration of alumina particles and dominated abrasive wear.

- Adhesive and abrasive wear mechanisms are found to be dominant in the case of 1% added alumina composite material.
- Coefficient of friction is observed to be lower for 1 % alumina added composite material compared to other materials.
- Pure ABS material is observed to have uniform wear and the composite materials exhibit non-uniform wear track due to the reduced wear rate.

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