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EROSION OF GLASS FIBRE REINFORCED EPOXY COMPOSITES

Atia A. M.[1] and Ali W. Y.[2]

[1]El Minia High Institute of Engineering and Technology, EGYPT,
[2]Production Engineering and Mechanical Design, Faculty of Engineering, El-Minia University, EGYPT.

ABSTRACT
Sand erosion of epoxy resin reinforced by randomly distributed glass fibres and filled by synthetic, paraffin and glycerine oils is studied. The effect of inclination of impact angle (30º, 60º, and 90º) and oil content (2.5, 5, 7.5, and 10 wt. %) contained in the matrix of epoxy resin is investigated. In addition, the electrostatic charge generated on the eroded surface is measured. Reinforced epoxy demonstrates low erosion resistance compared to unreinforced epoxy. SEM surface examination reveals the effect of inclination angle on wear. Specimens filled by oil lose the electrostatic charge generated from sand erosion in earlier time compared to the unfilled test specimen.

KEYWORDS
Erosion Resistance, Epoxy, Glass Fibers, Electrostatic Charge.

INTRODUCTION
Solid particle erosion is a general term used to describe mechanical degradation (wear) of any material subjected to a stream of erodent particles impinging on its surface. The wear mechanism is affected in many industrial and engineering components. There are still wear problems present in mechanical applications, [1 - 4].

Composite materials, usually shortened to composites, are engineering made from two or more constituent materials with significantly different physical or chemical properties, which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. As matrix and reinforcement materials are the basic components of composites, the reinforcement materials play an important role in forming any composite material. This is so because when materials of varying specifications are imposed into a matrix, these materials significantly improve one or more operating properties of the newly formed composite, [3, 5 - 7].

In addition, composites acquire an important place when it comes to operating in a dusty environment where resistance to erosion becomes an important factor, [6, 8]. However, composite materials with different specifications were subjected to different erosion experiments. Solid particle erosion wear, which results from solid particles moving at various velocities and impingement angles striking the surface of a material is one of the most significant types of wear, [8]. For example, nuclear piping systems experience erosion from corrosive products, gas turbines and wind turbines are exposed

to sand particle impacts and helicopter rotors can experience significant damage from airborne particles. In the energy production sector, sand from reservoirs is frequently produced along with oil and gas and erodes piping components and equipment in the reduction path, [9, 10].

Triboelectric charging of polymers is a widely known phenomenon. It is found in numerous engineering technical applications, like electrophotography, electrostatic copy and printing techniques and colouring. The different charging behaviour of different polymers opens the possibility to apply this phenomenon to separate mixtures containing various polymers. The majority of published investigations to separate polymers species from their mixtures discusses technical principles, their prospects as well as limits, and macroscopic factors influencing the triboelectric charging, [11]. The electrostatic charge that most of us are familiar with is generated when two material surfaces in close contact are rubbed against each other or are separated from each other. When taking off a synthetic garment, for instance pulling a sweater overhead, one experiences sparks due to having generated electrostatic charge. The charge build up is influenced by factors such as speed and contact pressure and charge build up is higher for surfaces with smaller surface roughness, [12, 13].

Many so-called triboelectric series have been published. In such a series, the samples are grouped according to their resulting charge with the positively charged samples at the top and the more negatively charged at the bottom of the tables. The triboelectric series have very little particle value since materials are getting more and more complex with additives, pigments, fillers etc. One may be led to believe that two sheets of the same material would not be charged when rubbing. In the real world, they do charge, which is a very serious problem in the handling of paper or plastics sheets in the graphics industry or in powder handling in the pharmaceutical and plastics industries, [14].

However, polymer and its composite exhibit poor erosion resistance as compared to metallic materials. It is also known that the erosive wear of polymer composites is usually higher than that of the unreinforced polymer matrix, [6, 15, 16]. For many years the researchers have dedicated their effort to investigate the phenomena of solid particle erosion.

A review article on the solid particle erosion of polymers and polymeric composites focusing on the failure mechanisms, the most discussed influencing parameters and the different trends observed in the literature was presented, [1]. A detailed analysis was given on the effect of experimental conditions and target material characteristics on the erosive response of polymers and polymer matrix composites. Beside, empirical relationships that attempted to correlate the erosion rate with some of the influencing parameters were reviewed. Finally, averaging rules and predictions were summarised.

The erosion efficiency of polymers and polymer composites was investigated, [6]. The erosion efficiency of these materials was represented as a function of their hardness in order to create erosion relations. In this map, a clear demarcation of elastomers, thermoplastic, thermosetting polymers and polymer composites is reflected. However, within the same group of materials, a scatter is found in the efficiency map. Therefore, the erosion efficiency can be used only as a baseline for estimation of the erosion

resistance of these materials. In the present work, sand erosion of epoxy resin reinforced by randomly distributed glass fibres and filled by synthetic, paraffin and glycerine oils is investigated. Besides, the electrostatic charge generated on the eroded surface is measured.

EXPERIMENTAL

Materials

Epoxy specimens were prepared by hand lay-up method in rectangle die, in dimensions of 90 × 90 mm and 3 mm thickness, Fig. 1. The epoxy is a product of JOTUN Company with a commercial name (jotafloor solvent-free primer b20). In this study, synthetic oil (5W40), paraffin and glycerine oils were mixed with epoxy of 2.5, 5, 7.5 and 10 wt. % oil content.

Fig. 1 Random glass fibres.

Figure 1 and table 1 demonstrate the random fibres and the properties respectively. The uniform dispersion of shorter fibres in a resin system is seemingly random, yet produces close to isotropic properties in the final cured material. Non-woven fibres and resin systems are much easier to be applied to an automated process and are, in general, less costly to produce than that of weaved, aligned fibres.

Table 1 Glass Fibre properties

Property	
Resistance to tension	2500 MPa
Density	(2.64 g/cm^3 – 2.66 g/cm^3)
softening point	(840 – 875 $^{\circ}$C)
filament diameter	(17 µm)

Hand Lay-up method was used as manufacturing technique to produce composites specimens. This method is a rapid and not expensive process, especially open mould one. Firstly, the components A (hardener) and B (resin) are mixed in ratio one to two. The most basic fabrication method for thermoset composites is hand layup, which typically consists of laying dry fabric layers, by hand onto a tool to form a laminate stack, Fig. 2. The resin is applied to the dry plies after layup is complete (e.g., by means of resin infusion). In a variation known as a wet lay-up, each ply is coated with resin and compacted after it is placed. Several curing methods are available. The most basics are simply to allow the cure to occur at room temperature. Cure time can be accelerated, however, by applying heat, typically with an oven, and pressure. The die consists of three major parts, Fig. 3.

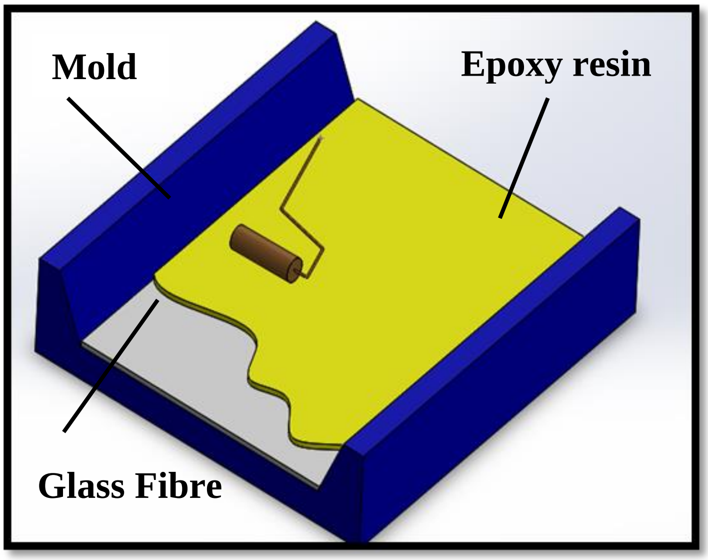


Fig. 2 The Illustration of lay-up method fabrication technique.

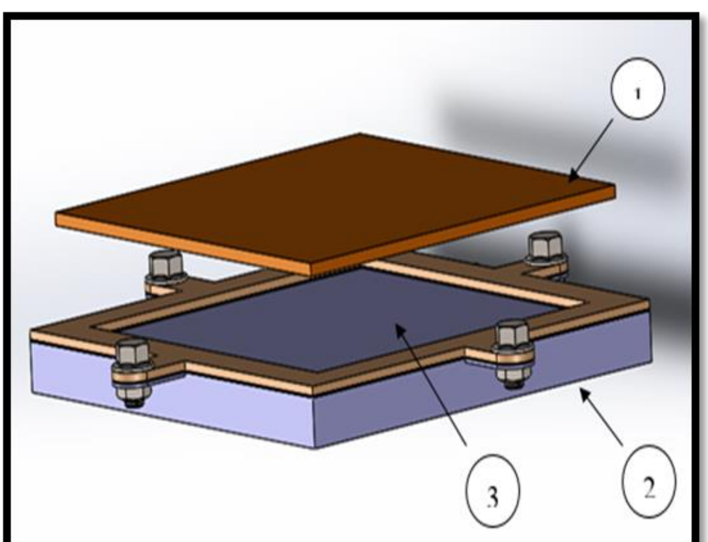


Fig. 3 Die setup: (1) Die cover, (2) Lower die and (3) Die cover.

Tests have been conducted on an erosion wear test apparatus, where the dry and compressed air is used to accelerate the abrasive particles to strike the test specimen. The sand particles are driven by air pressure at room temperature. The time of the test was 4 min. at approximate steady air pressure. Tests have been performed in a sandblasting chamber, Fig. 4. The distance between the sample holder and the nozzle was 60, 100 and 160 mm corresponding to 6, 7.2 and 9.5 m/s particle velocities. The impact angle has been adjusted by tilting the sample holder. Three impingement angles were selected 30, 60 and 90º. The erosion tests have been operated at room temperature, Table 2.

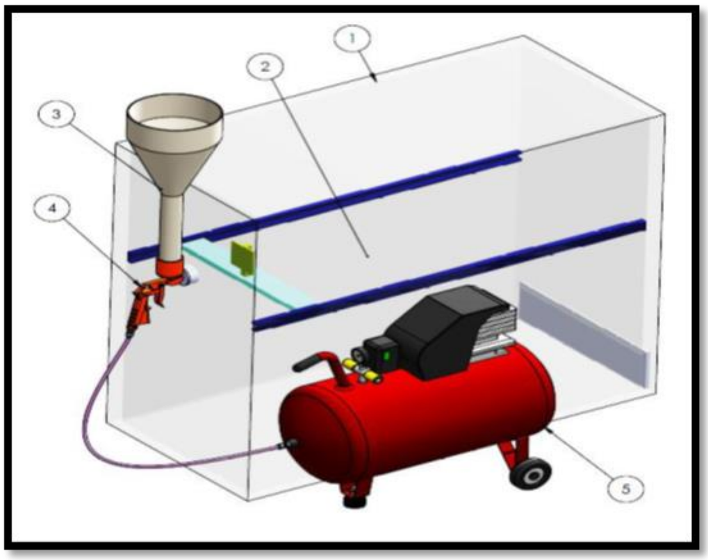


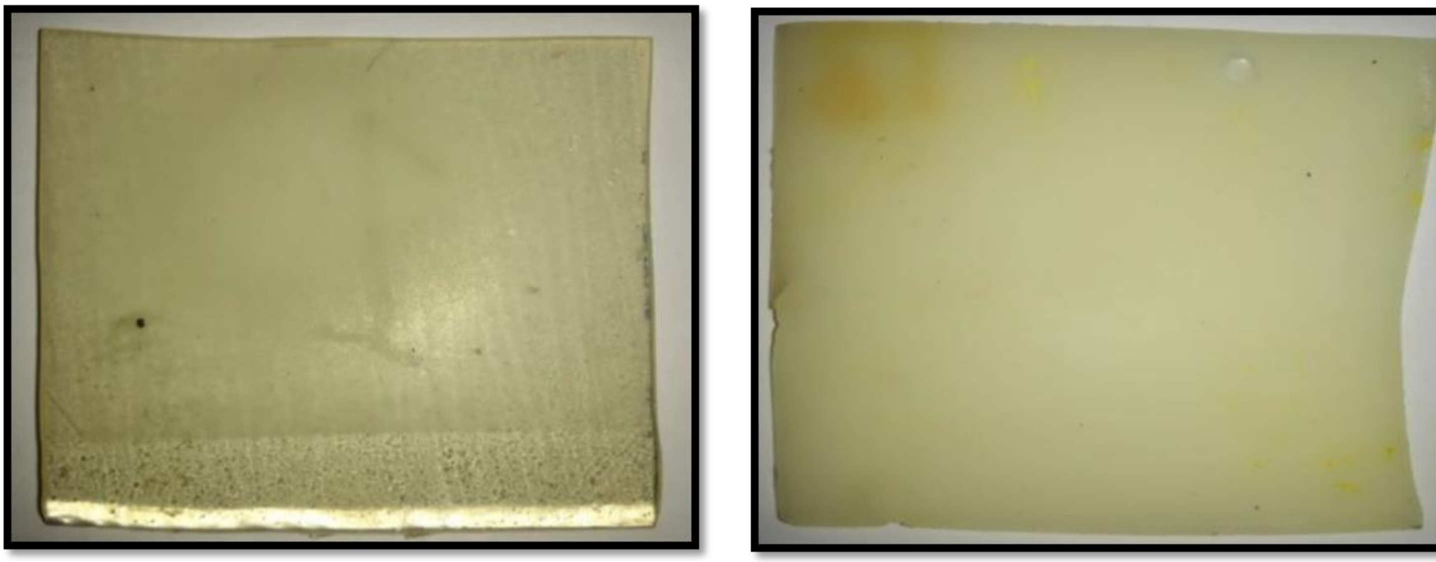
Fig. 4 Sand Erosion Apparatus: (1) Sandblast Chamber, (2) Specimen, (3) Sand Abrasive Container, (4) Abrasive Gun And (5) Air Compressor.

Table 2 Test parameters

Test Parameters	
Erodent Type	**Silica Sand**
Erodent Size (μm)	**600 - 650**
Impingement Angle	**30, 60, 90˚C**
Impact Velocity(m/s)	**6, 7.2, 9.5**
Test Time	**4 minutes**
Test Temp.	**Room temperature.**
Nozzle Diameter	**3 mm**

RESULTS AND DISCUSSION

It can be noticed from Fig. 5 that the transparency of epoxy used in the present work is reduced due to the addition of synthetic oil. Obviously, the property of transparency is an advantage of clear epoxy but the benefits of adding oil are planned to be investigated in the present work. Adding oil to epoxy matrix before curing made the composite as a self-lubricant material.



(a) (b)

Fig. 5 (a) Unfilled specimen with oil, (b) Specimen with oil.

It is well noticed that, impact velocity, impingement angle, size of particles, their hardness, shape, type and flow rate plus the properties of target material and environmental parameters, all have effects on erosive wear. The effect of angle of inclination tends to show variations in the behaviour of the material tested were ductile, semi ductile or brittle. The pervious studied factors have generally shown that the maximum erosion rate of ductile materials occurs at impingement angle of 30º, whereas maximum erosion rate of brittle materials occurs at 90º. The maximum erosion rate of semi ductile materials was found to occur at impingement angle of 60º.Figure 6 shows the effect of adding synthetic oil to unreinforced epoxy on wear at three different impact angles. It is obvious that increasing synthetic oil content decreases wear. The minimum wear takes place at 5 wt. % oil at all inclination angles. In addition, minimum wear occurs at 90º inclination angle. The reason of that behaviour is the oil content, which makes the surface more ductile and sponge to absorb the sand impacts.

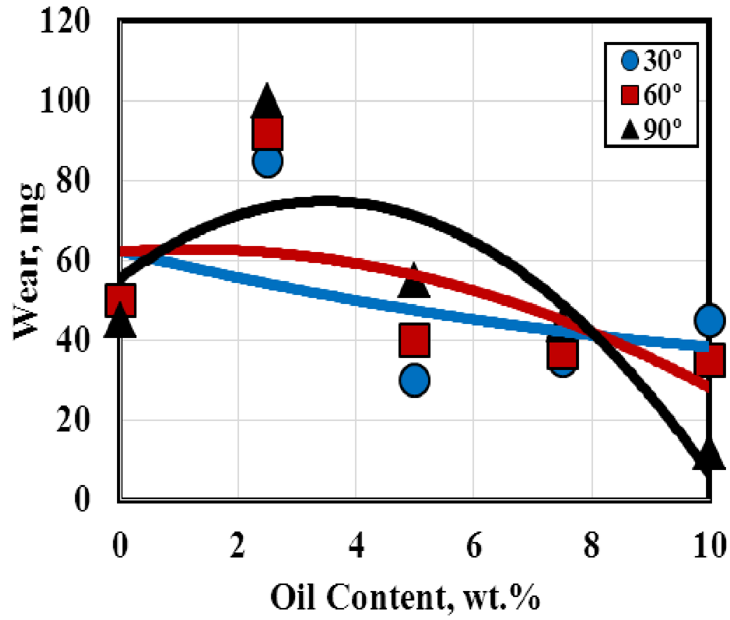


Fig. 6 The relationship between wear and synthetic oil content at different impact angles.

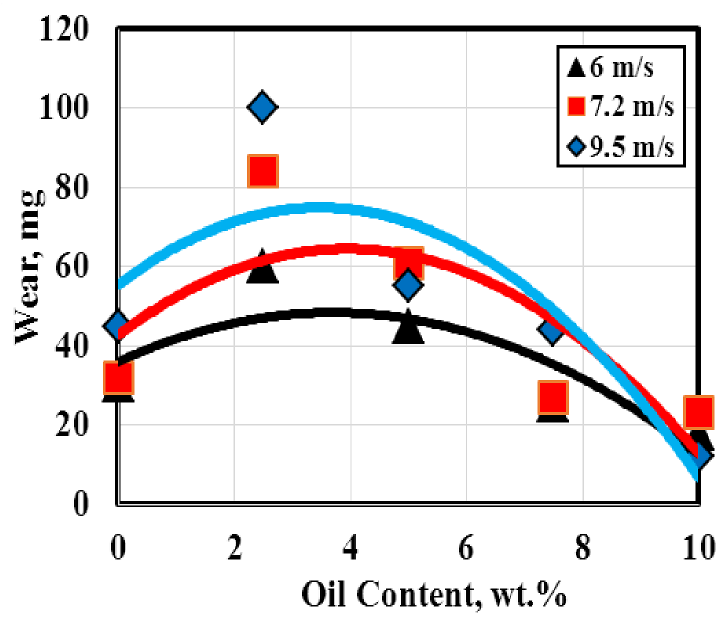


Fig. 7 The relation of the wear and synthetic oil wt. % content at three different impact velocity, 90° impact angle.

The influence of synthetic oil content in the specimen wear is presented in the Fig. 7. It is clear that the wear decrease for the lower value of impact velocity. It can be noticed the significant decrease in wear at 10 wt. % oil content at three the impact velocity. However, the effect of impact velocity is remarkable in decreasing the values of wear. Direct impact led to increase the wear at brittle material such as 0 and 2.5 wt. % oil content.

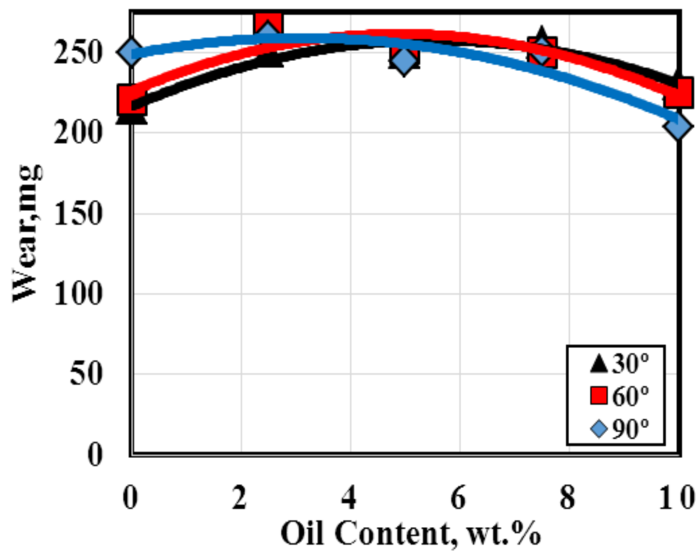


Fig. 8 The relationship between wear of specimen and synthetic oil content for epoxy composites at diffreant impact angles.

Figure 8 illustrates the effect of adding synthetic oil to epoxy reinforced by random glass fibre on wear. It is noticed that, with increasing oil content wear decreases. This result attributed to the diverting of specimen surface from brittle to ductile surface. This change in the behavior led to plastic deformation with minimum tearing can be recorded The maximum wear takes place at 2.5 wt. oil content. Besides, 90° inclination angle shows the minimum wear for the 7.5 and 10 % oil content. It is obvious that 5 wt. % oil content shows a remarkable value in wear value for impact angle 30°.

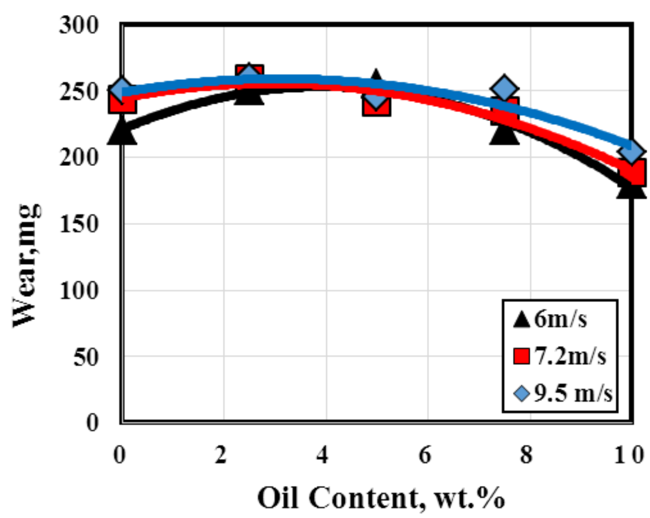


Fig. 9 The relation between the wear and synthetic oil content.

The demonstration of the effect of synthetic oil content on wear is shown in Fig. 9. It is obvious that wear decreases with increasing oil content, where 2.5 wt. % oil content shows a reduction in wear. However, there is remarkable increase in wear value at 5 and

7.5 wt. % oil content. On the other hand, minimum wear value has occurred at 10 wt. % oil content.

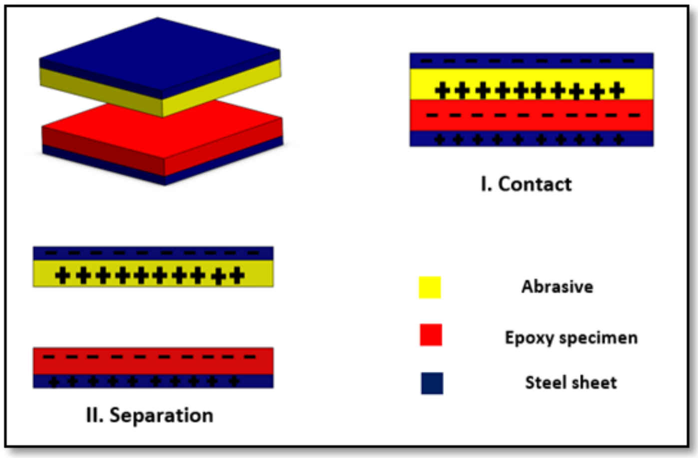


Fig. 10 Illustration of electro static Charge genrated from erosion.

Figure 10 shows the mechanism of electrostatic charge generated in the surfaces of the contact. It was clear from the figure that when two different materials are in contact, one of the surface will be positively charged while the other will be negatively charged. On the other hand, in releasing stage each of the material hold its charge that will produce direct current can be measured.

In sand particle erosion process, the principle of the electrostatic charge generated is shown in Fig. 11. The mechanism can be summarised into three situations rebounding and embedment. The rebounded particle behaviour is similar to pressing and releasing process to produce electrostatic charge. Embedded sand particle causes not electrostatic.

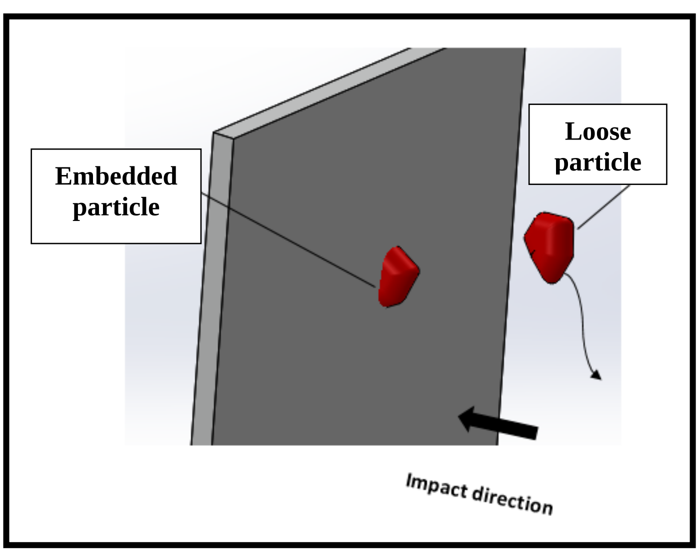


Fig. 11 The Mechanism of generating elecrostaic charge during erosion process.

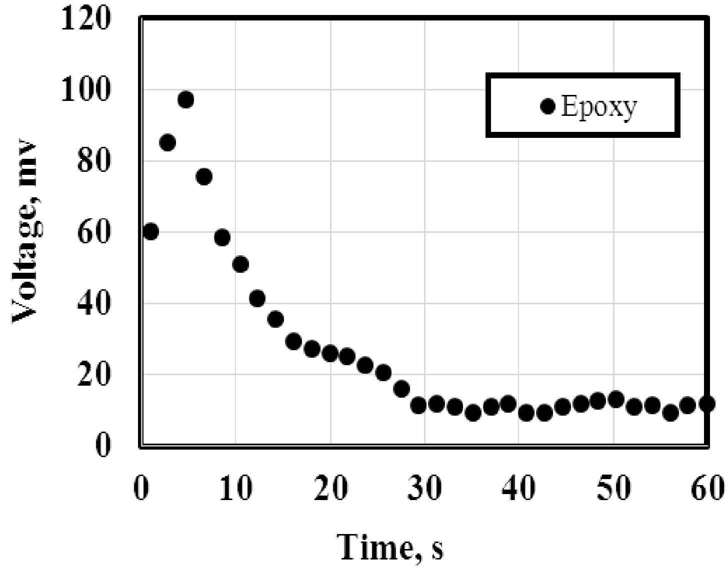


Fig. 12 The relation between valtages and time for unfilled epoxy.

The demonstration of the relation between electrostatic charge and time for epoxy specimen is presented in Fig.12. It can be noticed that the charge recorded a significant value close to 1.0 volt. However, this value tends to decay during the time of the test. In addition, the values are quite steady from the middle to the end of the test.

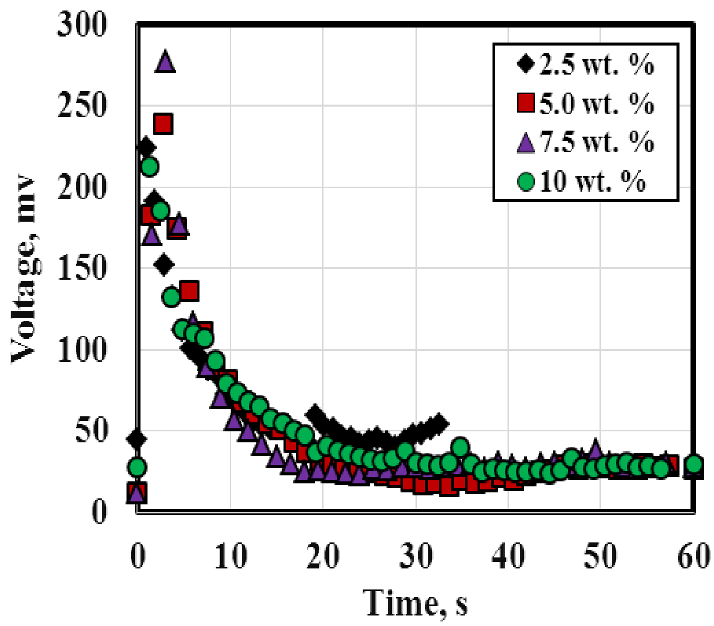


Fig. 13 The relation between voltage and time for epoxy filled by paraffin oil.

Figure 13 shows the behaviour of electrostatic charge (ESC) generated from solid particle erosion for epoxy filled by paraffin oil. It was clear that the maximum value occurred at 7.5 oil content at the third second. In addition, the value of (ESC) closes to be consistent after 15 seconds. However, there is slight decrease of charge can be recorded with the increase of oil content.

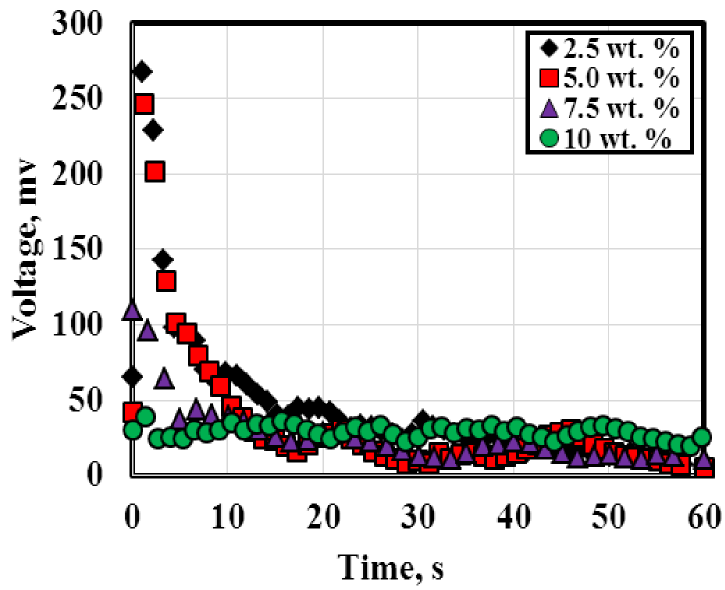


Fig. 14 The relation between charge and time for epoxy filled by glycerine oil.

Figure 14 demonstrates the value of electrostatic charge against the time in sand erosion process for epoxy filled by glycerine oil. It can be noticed that the value of charge decreases with an increase of oil content. On the other hand, there is maximum value recorded at 2.5 % oil content.

The illustration of the relationship between electrostatic charge generated from the epoxy sample in solid particle erosion and motor oil content showed that as the oil content increases the (ESC) increases. The maximum value of (ESC) takes place in 10 % oil content at the beginning of the test. The lowest value can be recorded for 2.5% oil content at the end of the test, Fig. 15.

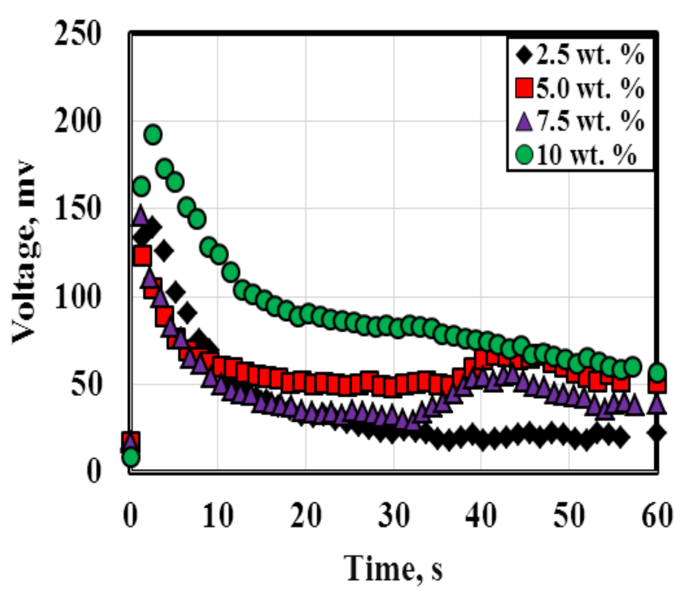


Fig. 15 The relation between electrostatic charge and time for epoxy filled by synthetic oil.

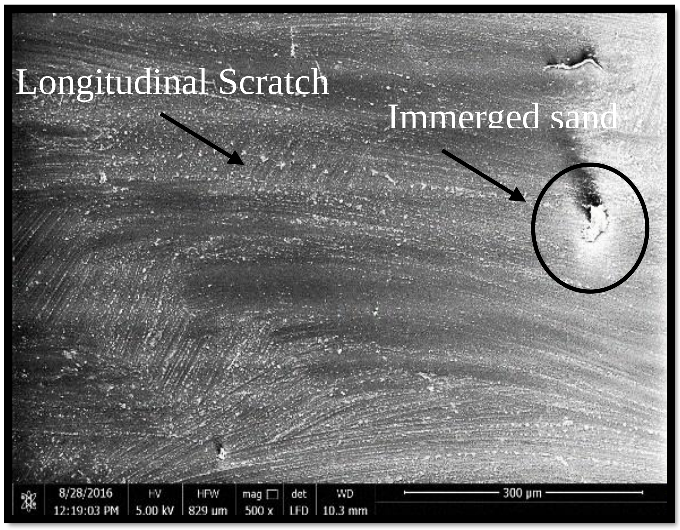


Fig. 16 epoxy specimen (impact velcoty 9.5m/s)(impact angle 90º) under SEM (500 X).

SEM examination shows epoxy at 500 X magnification Fig. 16. Lines can be seen in the surface of the specimen due to preparation technique. In addition, it is obvious that there is a groove in the surface with dimensions near to 22 µm, in the dashed area, which indicates the sand penetration. However, there are some of the sand particles sticking in the specimen surface with partial penetration. This type of penetration will lead to more wear because this sand particle could be easily removed in the following erosion situation. In addition, there is a remarkable scratch can be easily noticed at the right bottom of the photomicrograph. It is clear that there are many numbers of tiny sand particle still keep embedded in the specimen surface. Furthermore, there are three large grooves with 200 µm length and 20 µm width. In addition, it can be clearly noticed the sharp built-up edges formed around the tiny groove. As was mentioned before, epoxy surface shows significant high erosion resistance compared to its composites.

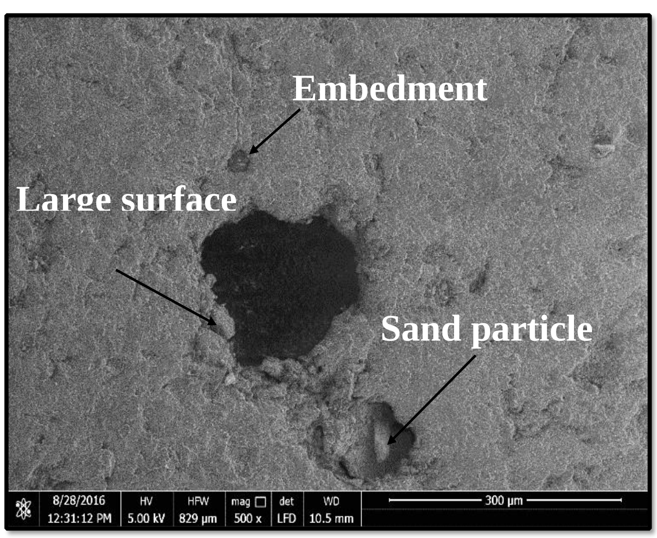


Fig. 17 Epoxy Specimen Filled with 10 wt. % syntheticOil Content(impact angle 90º) Under SEM (500 X).

The illustration of sand erosion process for epoxy filled by 10 wt. % synthetic oil is shown in Fig. 17. The unreinforced unfilled epoxy specimen still shows good erosion resistance. This investigation shows spongy surface. Micro cracks and large surface cavity are presented clearly in the surface. However, there is a relatively big cavity with rounded edges. The dimension of this cavity is 177 µm approximately. In addition, there is a second cavity that has an embedded sand particle in the bottom of the hole. The dimension of a small cavity is about 128 µm. There is remarkable embedded sand particle of sharp corners of size close to 176 µm. This cavity could be created from sharp corners sand particle that hits the surface.

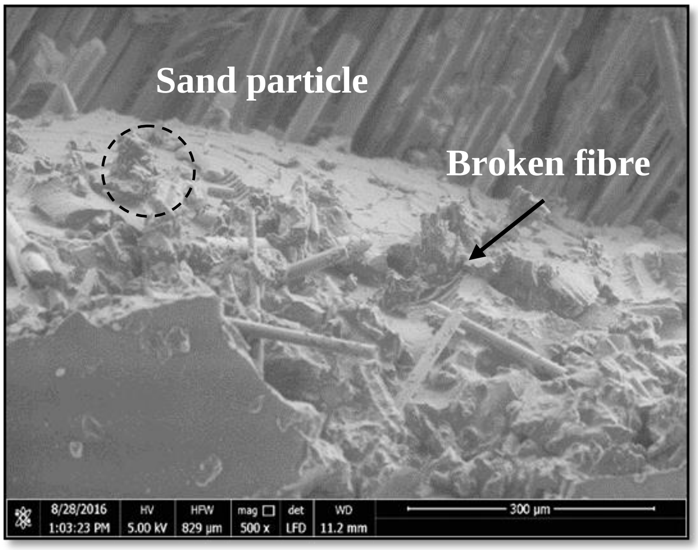


Fig. 18 Reinforced Epoxy with Random Glass fibres Filled by 10 % Wt. synthetic Oil Content Under SEM 500 X.

Epoxy reinforced by random fibreglass filled by synthetic oil is presented in Fig. 18. It can be easily observable that there are too many fibres that fractured and dislocated from there places. Nevertheless, there are some of the built up edges. However, there are embedded sand particles of 150 µm particle size. It can be seen the break of fibres due to impacted sand particle. Also, there are many cracks of epoxy in sharp and rounded shape. In addition, it can be seen clearly that there are ductile dislocation and surface tearing in the surface of the eroded edge. It can be concluded from the observations of the eroded surfaces that the random fiberglass specimen shows significantly low wear results.

CONCLUSIONS

1. The erosion mechanism of epoxy is brittle behaviour with the maximum wear value at 90° impact angle.
2. The erosion of epoxy reinforced by random glass fibre shows higher value of wear compared to unreinforced epoxy.
3. The increase in velocity of sand particles leads to increase the wear values for composites filled by synthetic oil.
4. There is slight decrease in electrostatic charge in epoxy specimen filled by paraffin and glycerin oil compared to synthetic oil.

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