European Polymer Journal 45 (2009) 149–154

Contents lists available at ScienceDirect

European Polymer Journal

journal homepage: www.elsevier.com/locate/europolj

An experimental investigation of wear of glass fibre–epoxy resin and glass fibre–polyester resin composite materials

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ARTICLE INFO

Article history:
Received 19 June 2008
Received in revised form 7 September 2008
Accepted 9 October 2008
Available online 17 October 2008

Keywords:
Polyester resin
Epoxy resin
Wear
Composite materials
Glass fibres
Woven fabric

ABSTRACT

In this paper, the effects of resin content on the wear of woven roving glass fibre–epoxy resin and glass fibre–polyester resin composite materials have been examined. Furthermore, composite materials are experimentally investigated under different loads and speeds by using a block-on-shaft wear tester. The influences of two thermosetting resins epoxy and polyester on the wear of glass-woven roving reinforced composites under has been investigated dry conditions. The glass fibre–epoxy resin and the glass fibre–polyester resin composite materials specimens have been tested under different experiment conditions. Tests were conducted for 0.39 and 0.557 m/s speeds, at two different loads of 5 and 10 N. The weight losses were measured after measuring different sliding distances. Wear in the experiments was determined as weight loss. For each experiment, one specimen was used. The amount of wear was measured before the experiment and after the experiment with the apparatus of balance scales with the accuracy of 10^{-3} g. Glass fibre–epoxy resin composites generally showed higher strength and minimum wear when compared with glass fibre–polyester resin composites materials. In addition, Scanning electron microscopy (SEM) is used to study the worn surface to verify the results.

1. Introduction

Composite materials are not new, since materials are known to have been used by the ancient Chinese, Israelites and Egyptians, all of whom embedded straw in bricks to improve their structural capabilities. Why composite materials, because, it has always been the hope of metallurgists to be able to produce structural materials possessing both great strength and extreme ductility. Great strength offers high load-carrying capacity. Composite materials became widely used due to their superior properties, such as low density and cost. Numerous applications have been allocated for these materials of automotive and aerospace industries such as bushes, seals, gears, cams, shaft, etc. [1–3]. Although reinforcement polymer with fibres enhances the tribo-properties of the pure resin, sometimes it can worsen them [2]. Most of the previous studies [2,4–6] concentrate on the wear and friction properties of polymeric composite material. On the other hand, surface temperature is another equally important parameter in studying tribological behaviour of polymeric composite, [1,7,8]. However, little attention has been paid to it. It has been indicated that in most polymeric composite, high stiffness and low thermal conductivity results in high temperature at the sliding contact during friction and beyond a certain critical temperature, wear rates were found to be increased very sharply [8,9].

The increases in the use of the composite materials mean that it is necessary to know their behaviours under working conditions. The wear resistance is an important parameter and its experimental behaviour must be known.

Composite materials are being preferred more and more instead of steels and other metals because of their high strength at low specific weight. Besides, wider choice of material and manufacturing glass-fibre-reinforced polymer (GFRP) still require a lot of handwork and it is rather expensive making them an ideal case for engineering

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doi:10.1016/j.eurpolymj.2008.10.006

applications [10–12]. On account of their good combination of properties, fibre-reinforced polymer composites are used particularly in the automotive and aircraft industries, the manufacturing of spaceships and sea vehicles [5,6]. Nowadays, non-metal composite materials are being widely used as an alternative to steel and other materials. There are two main characteristics which make these materials attractive compared to conventional metallic designs. Many studies about the sliding wear mechanism of glass-fibre–polyester composites have been carried out. When epoxy resins are reinforced with high-strength glass-fibres, the product obtained is used in structural applications requiring high strength and low weight [23,24].

They are of relatively low density and they can be tailored to have stacking sequences to provide high strength and stiffness in the directions of high loading [14]. Composite materials consist of a resin and reinforcement chosen according to the desired mechanical properties and the applications [15,16]. Among the fibre reinforcements; glass, carbon and aramid fibres are the most likely candidates and are widely employed. Polymer composites reinforced with these fibres are usually one to four times stronger and stiffer than their unfilled equivalents [17]. Among the resins, polyester, epoxy, phenolic and silicon resins are the most likely candidates and are widely employed.

The ever-increasing demand for reliability and long life of machines is one of the main problems of contemporary engineering [18]. In on industry, materials particularly. Working in places under wear effects are desired to be wear resisting. For this reason, the wear resistance of the materials must be known [13]. Wear (DIN 50320) is called as occurring non-desired modifications with deviation of little pieces due to a mechanical cause or energy on surface of the material [19].

Many studies reported that the wear resistance with polymer sliding against steel improved when the polymers are reinforced with glass or aramid fibres. However, the behaviour is affected by factors such as the type, amount, size, shape and orientation of the fibres, the matrix composition and the test conditions such as load, speed and temperature [17,19,22]. The wear resistance of materials is determined in the laboratory experiments. In this study, the wear behaviours of woven glass fibre, composite materials are investigated under different loads, speeds and sliding distances.

2. Experimental procedure

In this experiment, composite materials were made of glass fibre–epoxy resin and glass fibre–polyester resin material. They had a quasi-isotropic stacking sequence, 90°, with the surface ply, which is contact during friction experiments having a 90° fibre orientation direction. Wear behaviour of the glass fibre–polyester resin (provided by Fiber Çağ, Turkey) and glass fibre-epoxy matrix resin (CYCOM7701) provided by TAI, Turkey are experimentally investigated. The woven glass fibre-reinforced composites made of 425 and 500 gm^{-2} (yarns can be produced from a wide range of fibres and whiskers. In the case of short fibres and whiskers, the yarn must be spun (or twisted) to hold the fibres together. Continuous fibres require no spinning, but it is often advantageous to do so. Fabrics are produced from these yarns by normal weaving processes). If the fibres are not spun the fabrics are usually denser, and involve much less fibre flexure. Plain wave glass fibre–polyester matrices contain E-glass fibres of diameter 10–24 μm. Woven fabrics should be used when high shear strengths are required in the plane of the reinforcing sheet. The more unidirectional weaves generally have lower shear strengths than conventional weaves. The glass fibre composites have been reinforced with the volume of fibres, $V_f = 30$ vol % and with the volume of matrix, $V_m = 70$ vol %. Matrix material used in these composites is polyester resin (Neoxil CE92). It is often desirable to add mineral filler to polyester resins. In addition to lowering the cost of resins, filler materials also improve the surface appearance, water resistance and reduce shrinkage. Polyesters are also commonly used as matrix materials, particularly with glass fibre reinforcement. Polyester is an economic material that has high chemical resistance and it is resistant to environmental effects. It has high dimensional stability and low moisture absorption. Low volume-fraction glass fibre–polyester composites with a wide range of colours have been in use for a long time. The production technologies for glass and thermoset glass–polyester composites are easier and cheaper than those for other glass–resin materials [5,6]. Glass-fibre-reinforced polymer with thermoset polyester resin is an attractive material that is economically desired. Its application at low temperatures and under service terms is easy, when this material is compared to advanced polymer composites with complex molecule structure, high strength and working under terms of difficult service [5,6,18].

This material is preferred due to the superiority of polymer mixed material, because it is easy to produce and at low cost, more than advanced engineering applications. It is being questioned the developed and improved properties of this material in present [14].

Epoxy resins of several families are now available ranging from viscous liquids to high-melting solids. Among them, the conventional epoxy resins manufactured from epiclorohydrin and bisphenol remain the major type used. Epoxy resins are also modified with plasticizers [5,6]. They are generally known as products using in structural component, adhesives, and protective plating due to their very good mechanical properties, chemical resistant and electrical characteristics. The shrinkage of epoxy is less than 2% and there is no water or volatile by-products generated during curing. When these epoxy resins are reinforced with high-strengthened fibreglass, the obtained product is used in structural applications to require high hardness and lightness [14,20].

2.1. Wear test details

The woven glass-fibre–epoxy matrix resin and the woven glass-fibre–polyester matrix resin composite materials were provided in the dimension of $310 \times 290 \times 3\ \mathrm{mm}^3$.

The experiment specimens with the dimension of $47 \times 27 \times 3\ \text{mm}^3$ were cut from the sheets.

The wear of composite materials was performed using a block on shaft test method Fig. 1. The abrasive used at the wear of specimens is SAE 1030 (DIN 22) steel that ground its surface and the diameters of 15 mm. The hardness and surface roughness (R_a) of the depreciator shaft are 150 HB30 and 1.25 μm, respectively.

The wear tests were performed on a specially prepared experimental set-up by using a lathe. The actual loads were placed on the pan of the load arm of this apparatus. The schematic view of wear set-up is shown in Fig. 1.

The role of experimental conditions is very important in experimental studies. First of all, the ambient conditions should not be changed during the experiment. The experiments were repeated if any change of the experimental conditions had been observed. A new experiment was performed after the shaft was completely cooled in all experiments. All the experiments were conducted at the room temperature.

The glass fibre–epoxy resin and the glass fibre–polyester resin composite materials specimens were tested under the different experiment conditions. Tests were conducted for 0.39 and 0.557 m/s speeds, at two different loads of 5 and 10 N. The weight losses were measured after measuring different sliding distances. Wear in the experiments was determined as weight loss. For each experiment, one of the specimens was used. Further, at the end of each experiment, debris on surface of the shaft was cleaned and then new were restarted experiments. The amount of wear was measured before the experiment and after the experiment with the apparatus of balance scales with accuracy of 10^{-3} g.

2.2. Analysis of worn surface

The microstructures of the worn surfaces were examined using the scanning electron microscope (SEM) at Tubitak Marmara Research Centre for better comments about the wear behaviours.

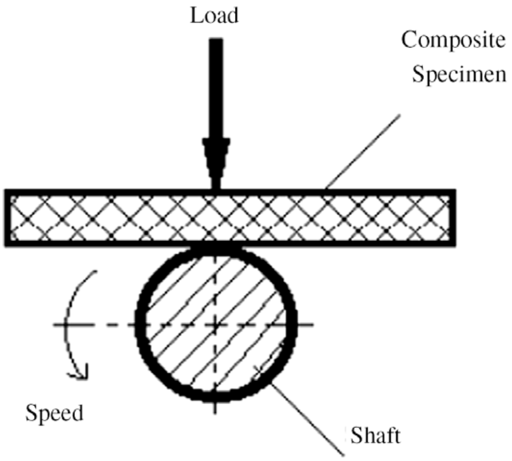

Fig. 1. Schematic showing a block-on-shaft wear test.

3. The experimental results and discussion

Load, sliding velocity, and sliding distance are the main parameter influencing the friction and weight loss. The effects of the normal load and the sliding speed on the weight loss of woven glass fibre, glass fibre–epoxy resin and glass fibre–polyester resin composite specimens are shown in Figs. 2–10, respectively.

The weight loss of the glass fibre–polyester resin composite specimens did not change below the sliding distance of 942 m, as shown in Fig. 2. However, the weight loss of the plain polyester resin increased above the sliding distance 942 m. This result may be explained with the increase of the temperature occurred at the experiments. The wear on the glass fibre–polyester composite decreases due to the effect of increasing temperature removal from the surface as illustrated in Fig. 10. The epoxy-based composite exhibits lower wear loss than that of polyester-based composite [21–24].

The weight loss is lower in glass fibre–epoxy resin composite specimens than in fibreglass–polyester resin composite under 0.39 m/s speed and 5 N load according to the sliding distance in Fig. 2. SEM photograph shows the features of worn surface at 0.39 m/s speed and 5 N load in Fig. 3.

The weight loss of all the composite specimens generally increased with the sliding distance at the constant sliding speed 0.39 m/s when the applied load was increased from 5 to 10 N (compare Fig. 2 with Figs. 4 and 5). Because the fibreglass–epoxy resin has a low friction coefficient and high wear resistance, the weight loss of the fibreglass epoxy resin is lower than that of fibreglass–polyester composite [5,6,18]. For this reason, the weight loss becomes less depending on the sliding distance as shown in Fig. 5.

The wear will occur in the polyester resin rather than the reinforcement. SEM photograph in Fig. 6 shows the features of worn surface at 0.557 m/s speed and 5 N load. Variation of weight lost with the sliding distance at speeds of 0.557 m/s speed and 5 N load shown in Fig. 7.

The woven glass fabric-reinforced composites were subjected to a larger weight loss depending on sliding dis-

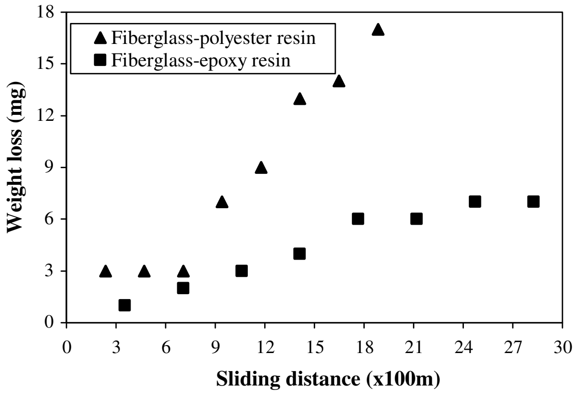

Fig. 2. Variation of weight loss with the sliding distance at 0.39 m/s speed and 5 N load.

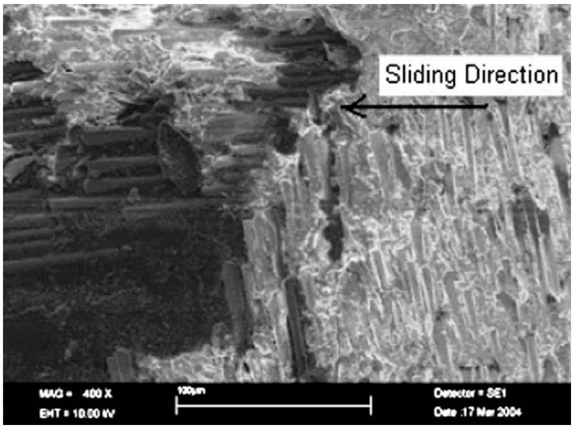

Fig. 3. SEM photograph showing the worn surface of glass fibre–epoxy resin composite at 0.39 m/s speed and 5 N load.

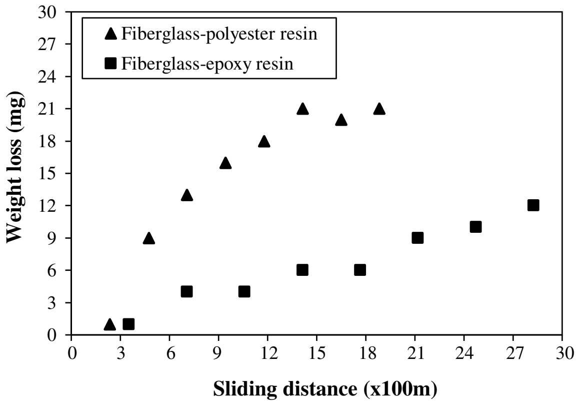

Fig. 4. Variation of weight lost with the sliding distance for 0.39 m/s speed and 10 N load.

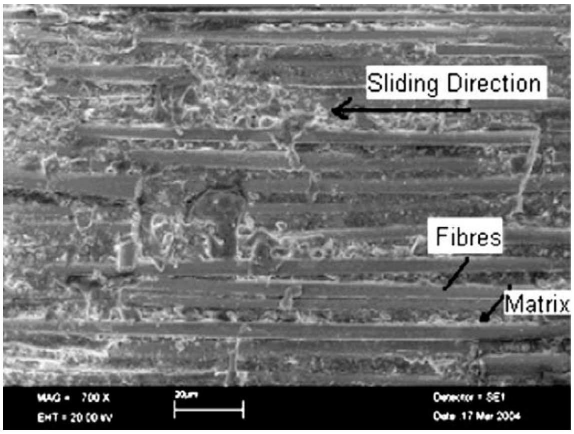

Fig. 5. SEM photograph showing the worn surface of glass fibre–epoxy resin composite at 0.39 m/s speed and 10 N load.

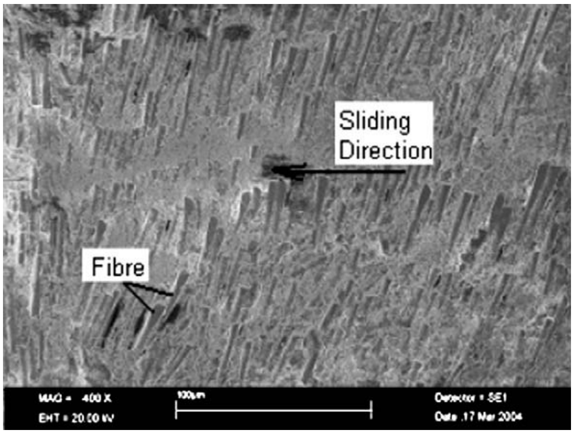

Fig. 6. SEM photograph showing the worn surface of fibreglass–polyester resin composite at 0.557 m/s speed and 5 N load.

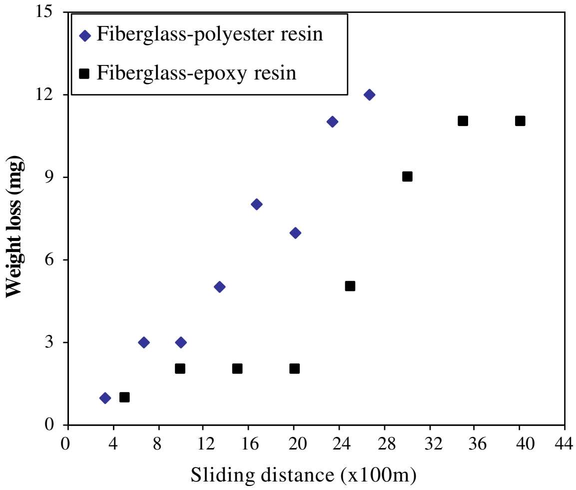

Fig. 7. Variation of weight lost with the sliding distance at 0.557 m/s speed and 5 N load.

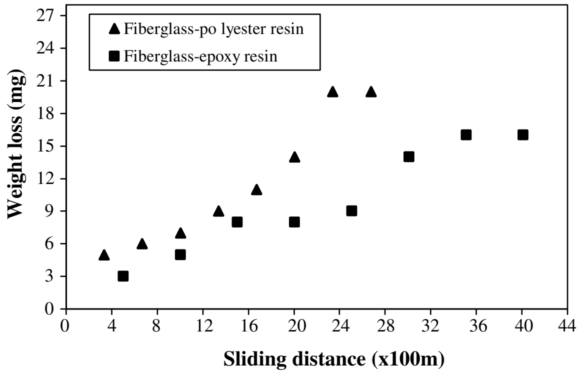

Fig. 8. Variation of weight lost with the sliding distance at speeds of 0.557 m/s, loads of 10 N.

tance, when both the sliding speed and the applied load are increased together as it can be seen in Fig. 8. It is well-known that the surface temperature plays an important role in the friction and wear of polymers and thus it increases at higher sliding speeds and loads [5,6,21].

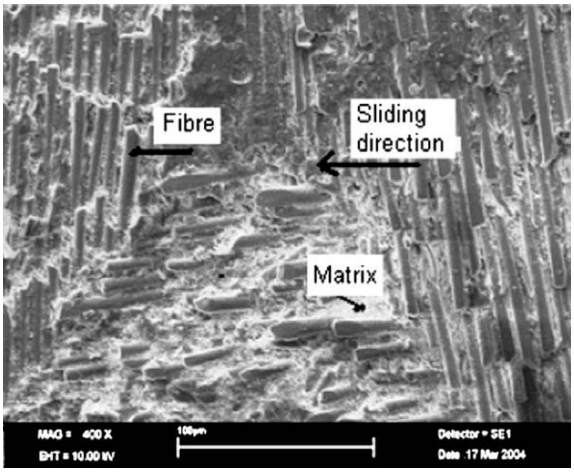

Fig. 9. SEM photograph showing the worn surface of glass fibre–epoxy resin composite at 0.557 m/s speed and 10 N load.

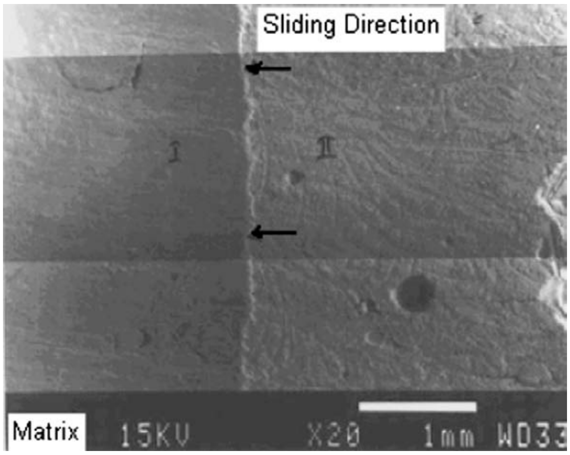

Fig. 10. SEM photograph showing the worn surface of glass fibre–polyester resin composite at 0.557 m/s speed and 5 N load.

By comparing Fig. 6 with Fig. 9, it is possible to highlight the effect of increasing load application on the wear surface features. At the high load situation it was observed that breaking in rows of fibres has increased in Fig. 9. The worn and unworn regions were marked with I and II on SEM photographs, respectively, in Fig. 10. The detached of the matrix at higher loads results in a loss of fibres thus contributing to the exposure of the fibrous region to sliding contact wear as well as fibre breakage [5,6].

4. Conclusions

After carrying the tribological investigation of glass fibre-reinforced polyester (CGRP) composite material, some conclusions can be drawn as follows:

The wear occurs in the matrix rather than the reinforcement. Therefore, the wear in the woven 425 gm^{-2} glass fabric-reinforced composite is lower than the woven 500 gm^{-2} glass fabric-reinforced composite keeping all test parameters constant. The wear in the woven glass fibre–epoxy resin composite specimens is lower than the woven glass fibre–polyester resin composite for all the speed and the load according to the sliding distance. Glass fibre–epoxy resin composites generally showed higher resistance and minimum wear if we compare with glass fibre–polyester matrix resin composites materials. The weight loss of the woven glass fibre–epoxy resin composite increased with increasing the load and the speed. The main reason for this increase is increasing the load and the speed causes an increase on the surface temperature of the material, therefore, the wear of the material is also affected depending on the amount and type of the fibre and resin.

The weight loss of all composite specimens generally increased with the sliding distance at the constant sliding speed, with 0.39 m/s, when the applied load was increased from 5 to 10 N. For this reason, the weight loss of glass fibre–epoxy resin composites less depends on the sliding distance.

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