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The Wear of Glass Fiber Reinforced Polyester Composite Materials at Different Loads and Speeds

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Abstract: Glass fiber reinforced polyester (GFRP) materials which are polymer matrix composites have some properties such as high specific strength, excellent elasticity, low weight, high corrosion resistance, high chemical resistance and high thermal stability. One of most important causes of failure of mechanical parts is wear. It is a surface property that can be reduced by changing the surface chemistries of the materials and microstructures. For this reason GFRP materials should be investigated not only for their mechanical properties but also for their tribological behaviours. The aim of this study is investigation of effects of different fillers and resins materials on adhesive wear properties of GFRP at different loads and speeds. In the sample production, different resins (reactive orthophtalic polyesters), reinforcing materials and fillers (glass beads, alumina) are used. . Initially, the samples were subjected to adhesive wear tests on two different loads (F=10N, F=20N) and two different speeds (n=100rpm, n=200rpm) at 150m sliding distance. The friction force and friction coefficient were measured during the test on tribometer. The densities of samples were measured. In the next step, the wear trace thicknesses were measured and the wear rates were calculated. In results, the addition of glass beads to plain orthophtalic polyester resin reduced wear rate. The influence of load effect on wear behavior of samples is more the influence of speed.

Keywords: Glass fiber; polyester; filler materials; adhesive wear.

Farklı Yük ve Hızlarda Cam Elyaf Takviyeli Polyester Kompozit Malzemelerin Aşınması

Özet: Polimer matrisli Cam Elyaf Takviyeli Polyester (CTP) konpozit malzemeler yüksek özgül mukavemet, mükemmel elastiklik, düşük ağırlık, yüksek korozyon direnci, yüksek kimyasal direnç ve yüksek termal kararlılık gibi bazı özelliklere sahiptirler. Makine parçalarının en önemli hasar sebeplerinden biri aşınmadır. Aşınma, malzemelerin yüzey kimyalarını ve mikroyapılarını değiştirerek azaltılabilen bir yüzey özelliğidir. Bu nedenle CTP malzemelerin sadece mekanik özellikleri değil, aynı zamanda tribolojik davranışları da araştırılmalıdır. Bu çalışmanın amacı farklı dolgu ve reçine malzemelerinin farklı yük ve hızlarda CTP malzemelerin adhezif aşınma özelliği üzerine etkisini incelemektir. Numunelerin üretimlerinde farklı reçineler (reaktif ortoftalik polyester), takviye malzemeleri ve dolgular (cam kürecik ve alumina) kullanılmıştır. Başlangıçta, numuneler 150m'lik sabit kayma mesafesinde iki farklı yükte (F=10N, F=20N) ve iki farklı hızda (n=100rpm, n=200rpm) adhezif aşınma deneylerine tabi tutuldu. Tribometre üzerinden test boyunca sürtünme kuvveti ve sürtünme katsayısı değerleri ölçülmüştür. Numunelerin yoğunlukları da ölçüldü. Bir sonraki adımda aşınma iz kalınlıkları ölçüldü ve aşınma oranları hesaplandı. Sonuçlarda, düz ortoftalik polyester reçineye cam kürecik ilavesi aşınma oranını düşürdüğü görüldü. Numunelerin aşınma davranışı üzerine yükün etkisi hızın etkisinden daha fazla olduğu tesbit edildi.

Anahtar kelimeler: Cam elyaf; polyester; dolgu malzemeleri; adhezif aşınma.

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1. Introduction

Composites have been used for a long time. Composites are useful materials because of their mechanical properties, chemical structure and tribological properties which are formed by combining two or more materials. These materials are matrix and reinforcements.

Polymers and their composites are extensively used in tribological fields because of light weight, resistance to corrosion, good strength to load capacity, self lubricating properties, better friction coefficient and better wear resistance [1]. Thermoset resins are used in polymer matrix composites because of their easy and cheap production methods such as; polyester, epoxy resin, vinylester and phenolic resin etc. Epoxy resins are widely used because of their good mechanical properties, high chemical and abrasion resistance, electrical properties [2]. But their cost is higher than polyester. Polyester is an economic material and resistant to environmental and chemical effects. It has high dimensional stability and low moisture absorption [1]. Such as; glass, carbon, aramid, natural fibers etc. the use of fibers as reinforcing material is widespread to improve the qualities of composite materials. Glass fiber (GF) is widely used in polymer matrix composites due to its high electrical insulation, resistance to moisture, good mechanical properties. Therefore, it is important to investigate composites containing glass fiber reinforcement and thermosetting resin. The production stages of thermoset glass / polyester composites are cheaper and easier than other glass / resin composite materials. The glass fiber reinforced polymer with thermoset resin is economical and remarkable [3,4]. Glass fiber reinforced polyester (GFRP) materials have resistant to different environmental conditions. GFRP materials are used in different industries such as construction, electrical-electronics, automotive, transportation, marine etc. due to high abrasion resistance, good corrosion resistance, high thermal resistance, excellent dielectric properties and lightness.

The fillers improve product properties, enhance product performance and provide surface smoothness. Alumina, glass beads (GB), calcium carbonate, carbon black etc. are used as filling material. It is considered that the tribological properties of the polymers will increase by the addition of filler material into the matrix material. Therefore, in recent years, importance has been attached to studies that investigate the effect of filler addition on wear characteristics [5,6]. The investigations have shown that the mechanical properties of polymer composites filled with small particles are good. Therefore, the mechanical and tribological properties of nanoparticle filled composites have been investigated [7].

Wear, was described as undesired material loss resulting in tribological stress in surface area of solid according to DIN 50320 [8,9]. Wear is generally described as the 4 main mechanisms. These are adhesion, abrasion, tribo-chemical reaction and surface fatigue. Adhesive wear bonding forces occur at contact between two materials. These forces are seen in interface of materials and are stronger than strength of surrounding area [10]. Adhesive wear is important for wear mechanisms. For this reason, the adhesive wear characteristics of GFRP materials must be investigated experimentally. The wear characteristics of fiber reinforced polymers (FRP) have been studied in many studies. GFRP material nano-Al_2O_3 particles were added in different volumes (1,2,3%) to investigate wear behaviors at different speeds and different loads. The wear resistance of the 3% nanoparticulate material was better than the others [11]. In another study, the resin effect on the wear behavior was investigated. Glass fiber reinforced epoxy resin material and glass fiber reinforced polyester material were tested at two different speeds and loads. Wear quantities were determined by measuring the weight loss after different sliding distances. Epoxy resin materials have less wear than polyester resin [12]. Bi-directional E-glass fiber reinforced polyester composites were filled with zinc oxide (ZnO) and titanium dioxide (TiO_2) and three-body abrasion tests were applied. It was seen that tensile strength decreased with filler, load, hardness and impact strength increased. TiO_2 coated composites showed better wear performance than ZnO coated composites [13]. The effects of different fiber reinforcements on the wear behavior were investigated in another study. Here, the carbon fiber reinforced epoxy composite materials and glass fiber reinforced epoxy composite materials were tested using three body abrasives at constant speed, two different loads and different sliding distances. Compared to carbon fiber reinforced epoxy composite with glass fiber reinforced epoxy composite, carbon fiber reinforced epoxy composite exhibited better wear resistance [14]. Glass fiber glass fiber reinforced polyester composites and plain polyester were subjected to abrasion tests at two different sliding distances, two different loads and speeds. Wear quantities were measured as weight losses at sliding distances. Glass fiber reinforced composite is less wear than plain polyester. Glass fiber reinforcement has been found to improve the properties of the material [1].

The aim of this study is investigation of effects of different fillers and resins materials on adhesive wear properties of GFRP at different loads and speeds. In this study, two different resins (ortophtalic polyester, tensile additive ortophtalic polyester) and fillers (Alumina, Glass beads) with different weight ratios were used in GFRP composites.

2. Materials and Methods

Tested Materials

The compositions and densities of GFRP samples using in experimental study are given in Table 1 and 2.

Table 1. Compositions of GFRP Samples

Sample	Matrix	Reinforcement	Filler
D1	Polyester	40 wt.% GF	10 wt.% GB
T1	Polyester	11 wt.% GF	1 wt.% Alumina
T2	Polyester + Tensile additive	11 wt.% GF	1 wt.% Alumina
T3	Polyester + Tensile additive	11 wt.% GF	5 wt.% GB
T4	Polyester	11 wt.% GF	1 wt.% Alumina + 5 wt.% GB
T5	Polyester + Tensile additive	11 wt.% GF	1 wt.% Alumina + 5 wt.% GB

Glass beads (GB) are used in various polymer composites because it improves lubrication. The GB have good interface strength. It reduces friction coefficient and wear. It also has characteristics such as lightness, low thermal conductivity, low dielectric constant [15-16].

Alumina has high strength and hardness, wear resistant, resistant to acids and alkalis at high temperatures. It used commonly at high temperature applications.

Table 2. Density of Samples

Sample	Density (g / cm^3)
D1	1,60
T1	1,73
T2	1,73
T3	1,70
T4	1,77
T5	1,76

In polyester production, %8 tensile is observed, which causes surface defects. Tensile additive is used to reduce the tensile ratio in the polyester and to improve the properties of the resin. The commonly used tensile additives are polyvinyl acetate homopolymer and copolymers, policaprolactam cellulose acetate butyrate and acrylic polymers.

Testing Procedures

GFRP samples were produced by hot-compression molding at 140˚C, 150 bar for 3 min. The used glass fibers in samples have 13 µm diameter and 12 mm length. GFRP samples were provided by Sami Tongün Glass Fiber Polyester Products, Kocaeli/Turkey for experimental studies. The samples having size of 20x20x4 mm were cut from the plate for wear test. The wear test of the samples was carried out on a ball on disc wear testing machine (Nanovea Tribometer). In tribometer, the ceramic ball with radius of 3 mm was fixed on the load arm and sample was placed on a rotating disc with a friction radius of 5 mm. In the experiment, the samples were subjected to two different loads (F=10N, F=20N) and two different speeds (n=100rpm, n=200rpm) at constant sliding distance (150m). The friction force and friction coefficient were measured during the test. Wear traces were determined by Nikon SMZ 745T light microscope. The wear rate values of samples were calculated according to test results. Hardness values of samples were measured by Zwick Barcol Tester. All tests were carried out at a constant room temperature (22˚C).

3. Results and Discussions

Figure 1 shows average friction coefficient of samples. Minimum friction coefficient at T2 and maximum friction coefficient at D1 were observed. Friction coefficient of T2, T3, T5 samples were lower than others. These samples have tensile additive orthophtalic polyester resin. When tensile additive resin is used together any filler (Alumina, GB), the friction coefficient reduced. The friction coefficient of samples with plain orthophtalic polyester was high. The use of alumina and glass beads together in two different polyester resins, increased friction coefficient.

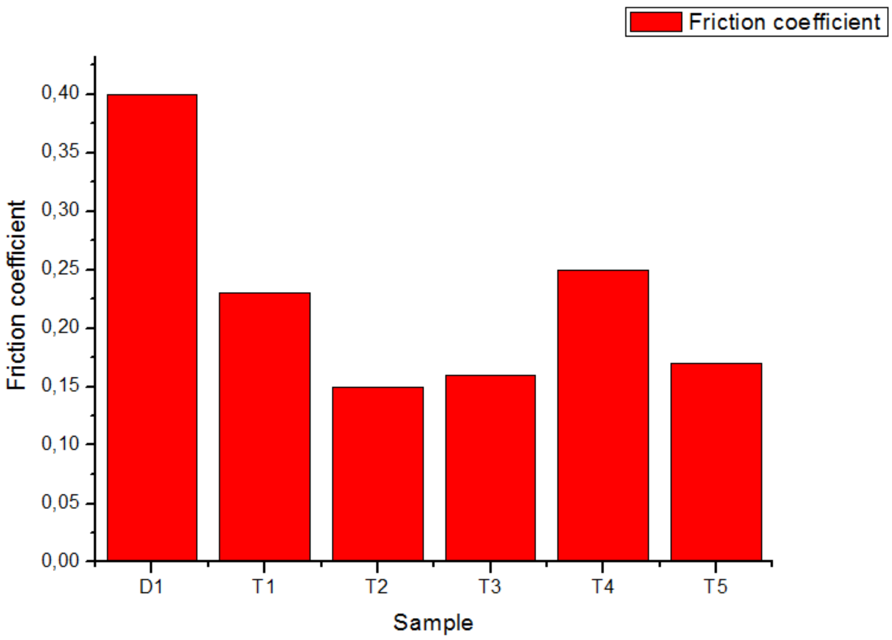

Figure 1. The average friction coefficient values of samples

The volume loss values of samples were calculated according to Standard test method (ASTM G99-05) by assuming that there was no significant pin wear [17].

$$V = \frac{\pi . R . D^3}{6 . r} \qquad (1)$$

Here V is the volume loss (mm^3), R is the friction radius (5 mm), D is the wear trace width (mm) and r is the ball radius (3 mm). The wear rate values of samples were calculated by following equation [18]:

$$k = \frac{V}{L.X} \tag{2}$$

Here V is the volume loss (mm^3), L is the load (N), X is the sliding distance (150m) and k is the wear rate (mm^3/Nm).

Figure 2 shows the wear rates of samples at 100 rpm and 200 rpm under 10 N load. In this figure, it was seen that the samples with low friction coefficient had lower wear rates. Wear rate values are high in GFRP samples which have no tensile additive. While wear rates of other specimens except for D1 are not changed too much with increasing speed, the wear rate of D1 decreases with increasing speed value. T5 has the highest wear resistance and D1 has the lowest wear resistance. In samples containing glass fibers at same ratios; Glass beads addition reduced wear. The sample which does not contain any tensile additive and contains alumina has maximum wear rate value in samples with same fiber ratio.

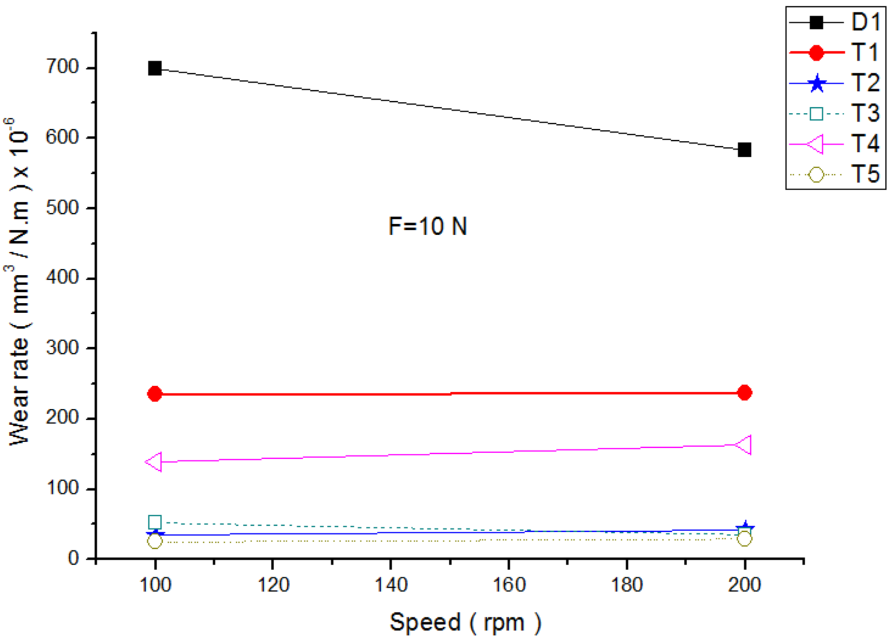

Figure 2. Wear rates of samples at different speeds (100, 200rpm), 10 N load

Figure 3 shows the wear rates at different speeds, 20 N load. The wear rate of T4 sample increased with increasing speed. But, the wear rates of other samples reduced. The greatest change in wear rate was seen at T2. The lowest wear was observed at T3, the highest wear was observed at D1. The use of tensile additive and orthophtalic polyester with glass beads under heavy load (F=20 N) increased wear resistance.

Increment of load increased wear rates values. The increment of load will increase temperature at the contact surface. As the polyesters become brittle with increasing temperature and detach from the surface, the wear resistance of material decreases [1]. The change in wear rates of T3, T4 samples is little. The wear rates of samples T3 and T4 did not change much in both increasing load values and increasing speed values. The wear rate of T5 sample did not change much with increasing speed. But it changed a lot with the increasing load. In general, T3 material has good friction properties. D1 sample has the highest friction coefficient and high wear. This situation may be related to increased glass fiber (GF) and decreased resin content. Fillers and reinforcing materials added to samples have different effects on various conditions. The use of glass beads as filler material is more effective than Alumina. Lubricating function of glass beads has reduced wear. When speed and load were increased together, the wear rates of other samples except for T3 increased. The wear rate of T3 didn't change. The addition of glass beads to the plain orthophtalic polyester resin decreased wear rate values. The addition of alumina filler into the tensile additive polyester increased the wear at 20N load. The alumina filler added to tensile additive orthophtalic polyester resin did not have a good effect on wear behavior. The use of glass beads as a filler in tensile orthophtalic polyester resin is more effective than alumina. The use of tensile additive orthophtalic polyester in samples containing alumina and glass bead together increases wear at 20 N load. In samples containing same weight glass fibers, the samples with plain orthophtalic polyester resin and alumina filler have the highest wear rate. In the experiments, the influence of load effect on wear behavior of samples is more the influence of speed. While the reinforcing and filling materials are adding to raw materials, it should be distributed into the sample taking into consideration features such as shape, dimension, size, surface characteristics and concentration [7]. Glass beads have lubrication function in plastics. T3 indicates that glass beads are used in correct amount because of less friction coefficient and wear rate. Glass beads and glass fibers are used too much in D1 sample. The using of high amount glass bead does not mean that friction coefficient and wear rate will be reduced. It is true that each filler and reinforcement material should be used in ideal conditions and proportions. If average wear rate values of samples under different loads and speeds are considered, T3 sample has the combination that leads to the most optimal result.

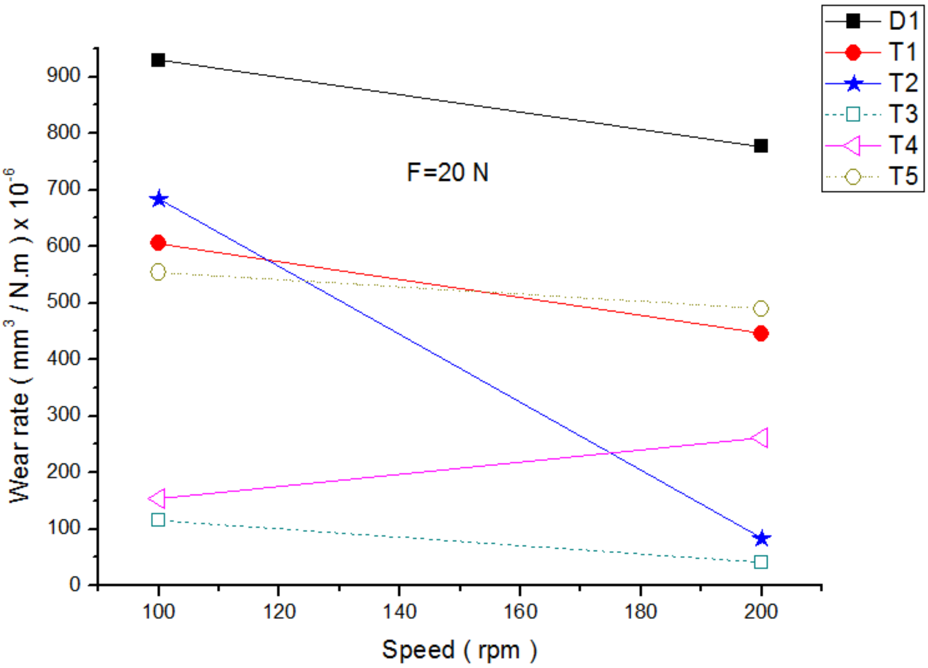

Figure 3. Wear rates of samples at different speeds (100, 200rpm), 20 N load

Table 3. Hardness of Samples

Sample	Hardness (Barcol)
D1	81
T1	81
T2	79
T3	70
T4	82
T5	77

4. Conclusion

- Tensile additive reduced the friction coefficient.
- The use of alumina and glass beads separately reduced friction coefficient but the use of alumina and glass bead together increases friction coefficient.
- The addition of glass beads to plain orthophtalic polyester resin reduced wear rate.
- In samples containing same weight glass fibers, the samples with plain orthophtalic polyester resin and alumina filler have the highest wear rate.
- The use of glass beads as a filler in tensile additive orthophtalic polyester resin is more effective than alumina for decreasing wear rate.
- The influence of load effect on wear behavior of samples is more the influence of speed.
- If average wear rate values of samples under different loads and speeds are considered, T3 sample has the combination that leads to the most optimal result.
- T3 sample has the minimum hardness value in the tested samples.

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