Available online at www.sciencedirect.com
ScienceDirect
Wear 261 (2006) 703–714
WEAR
www.elsevier.com/locate/wear

On the SEM features of glass–polyester composite system subjected to dry sliding wear

J. Quintelier [a,*], P. De Baets [a], P. Samyn [a], D. Van Hemelrijck [b]

[a] *Laboratory Soete, Ghent University, 9000 Ghent, Belgium*
[b] *Department of Mechanics of Materials and Constructions, MeMC,*
Free University Brussels (V.U.B.), 1050 Brussels, Belgium

Received 28 March 2005; received in revised form 28 November 2005; accepted 12 January 2006
Available online 3 March 2006

Abstract

Wear mechanisms of glass fiber reinforced polyester composites subjected to sliding wear for loads ranging from 60 to 300 N at a constant speed (10 mm/s) are studied by scanning electron microscope (SEM). The friction and wear tests are carried out, in dry conditions, on a newly built pin-on-disc machine with a rotating composite disc and fixed steel pin. The composite disc is cut out of pultruded plates, revealing a specific structure.

The classical laws of fiber orientation and their relation to friction can be proven in one single test, while the development of a thin film layer lowers the overall coefficient of friction, with almost 20%. Further on there is a clear relation between the coefficient of friction and the material structure. Also the importance of the fiber orientation and the relation to the wear of the pin sample are clearly shown.

The experimental results have shown that there is an existence of noticeable features on the worn surfaces. The use of SEM images in the study of this film formation and in the wear mechanisms of these materials gives an indication of the importance of shear forces on the wear behavior of these materials.

Keywords: Pin-on-disc; Wear mechanisms; SEM observations; Thin film; Friction; Composite

1. Introduction

The study of the wear behavior of polymers in general and polymer based systems in particular is finding increasing citations in literature [1] due to the availability of wider choice of materials, ease of manufacturing, good strength and light weight. An area where their use has been found to be very effective is the situation involving sliding contact wear [2]. The polymer-based materials are preferred in recent years over metal-based counterparts in view of their low coefficient of friction [3] and ability to sustain loads. This has given an impetus to industrial production of the materials, as for instance in the production of bearing components used in automobile industries [4] such as gears, cams, wheels, etc.

However, the deployment of fiber reinforced composites as components for use in actual service requires good understanding of the processing related structure and its influence on wear and friction.

A number of studies on polymer matrix composites subjected to sliding and abrasive wear indicate that wear resistance depends on the detailed properties of the material as well as the external wear conditions such as applied pressure and contact velocity [4]. Furthermore, fiber addition to polymers does not necessarily improve their wear resistance [5]. In the case of dry sliding it is effective in reducing the wear rate, for instance for the adhesion and fatigue types of wear [6]. This reduction in wear is due to the load carrying capacity of the fibers, their higher creep resistance and thermal conductivity. But the higher load makes it more sensitive to fiber breaking, pulverizing of the fibers, and transfer [7]. The effect on friction and wear of carbon fiber orientation and surface temperatures of unidirectional fiber composites were also investigated in detail by Tripathy and Furey [8]. Lu and Friedrich [9,10] studied systematically

---

* Corresponding author. Tel.: +32 9 2643276; fax: +32 9 2643295.
E-mail address: Jan.Quintelier@UGent.be (J. Quintelier).

0043-1648/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2006.01.006

the influence of carbon fiber volume fraction of their composites on friction and wear, and declared that an optimum range for short carbon fiber in PEEK matrix is 15–25 vol% according to the improved specific wear rate.

Also the relationship between formulation and performance is not clear and complex problems involving instabilities in the coefficient of friction, excessive wear, vibration, and noise accompany the friction processes of polymer matrix composite materials [11]. A friction process is always accompanied by the development of wear debris, which adheres to the rubbing couple [12–15]. As a result, a characteristic friction layer (thin film) forms on the surface, and this thin film determines performance [15]. The properties of these films play an important role in their tribological properties [16].

Keeping these aspects in mind, the response to dry sliding wear of glass fiber reinforced pultruded polyester has been looked into. After wear runs the mating surface of the composite is recorded using scanning electron microscope (SEM) [17], and also the cross-section of the resulting wear track is recorded, in order to determine explanations on the resulting wear and frictional behavior of these fiber composites.

2. Materials and methods

2.1. Test rig

A new pin-on-disc test rig (Fig. 1) was built in order to be able to monitor the tribological behavior of composite materials as bearing material. Our newly build test rig differs from those currently used in literature, where a composite pin is worn against a steel disc [18–21], in such way, here, a composite disc and a steel pin is used.

The pin (7), made of steel, with a length of 35 mm is hollow at the top, because to measure possible bending of the pin with strain gauges as a too stiff construction only results in measuring noise. Two flat parallel faces very near the contacting surface are places for an accelerometer (see inset Fig. 1A) and an acoustic emission sensor. The mating surface, or the bottom of pin, is a ball, from a ball bearing (Ø 8 mm), which can be easily replaced to get a multiple use of the pins (see inset Fig. 1B).

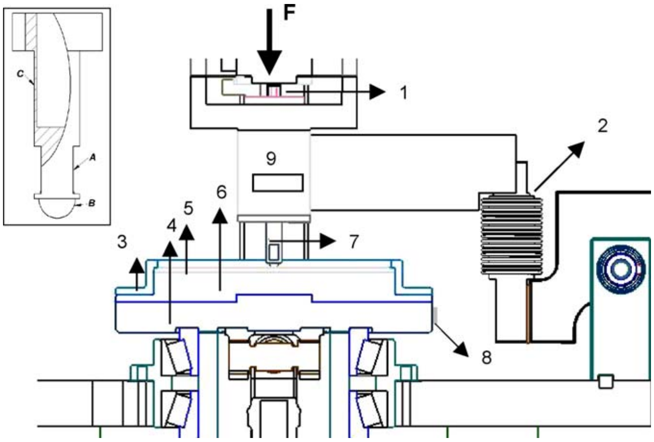

Fig. 1. Pin on disc test rig, with (1) normal load cell, (2) friction load cell, (3) ring for keeping the composite disc fixed and in the center, (4) fixed disc on the test rig, (5) composite disc, (6) removable disc where the composite test specimen is glued on, (7) pin, (8) magnets for triggering, (9) contact less proximitor counter face, inset: pin configuration, with A: a flat zone to put extra sensors on the pin, B: the mating surface, a ball from a ball bearing, C: the hollow pin construction.

Table 1
Final characteristics of the test rig

Sliding velocity	10–100 mm/s
Test specimens	Disc of Ø 160 mm with thickness of 3 mm
Maximum friction force	500 N (max. capacity of the loadcell)
Normal load	Up to 1000 N
Online camera	
Sensors	Thermocouple(s) Accelerometer (3D) Strain gauges Acoustic emission
Wear depth	Up to 1600 μm

Final characteristics of this test rig are: speeds from 10 to 100 mm/s, a possible normal load up to 1000 N, and the possibility to place additional sensors on the pin (2) (see also Table 1) for further research.

For the measuring of the depth of the wear track, a contact less proximitor (9) is used, which will give a relative indication of the wear depth in time.

For measuring the normal force on the pin a load cell is placed above the pin (1). This load cell is protected by a spring mechanism that allows pressing directly on it, without damaging the weakest parts of this measurement equipment. Another method to measure the normal force on the pin is by measuring the air pressure in the cylinder used as supplier for the normal force. This cylinder is connected via valves to the compressor. The friction force is measured with a load cell (2) based on bending.

On the rotating disc (4) magnets (8) are placed, which are needed to indicate the fiber orientation in the discs. This is achieved by placing three magnets. The first one alone and the other two together, separated by 180°. The single magnets is used to indicated the 0° disc position, the double magnet for the 180° disc position. Measuring these magnets together with the other signals for one round gives in the measured data indication of the 0° and 180° disc position, so the fiber orientation in these files can be found by visualizing measured signals, where the magnets are 1 for 0° and 180° disc position, and 0 for all other positions. They are also used as trigger for various signals. This type of indication is very reliable, and gives the possibility to calculate the values of the friction force related to a specific orientation (0°, 90°, 180°, 270°). These magnets also give an indication of the exact position on the disc where a measured type of signal comes from.

On a steel disc (6), the composite disc (5) is fixed with bee wax. Due to high loads this might not be enough to keep the disc in position, and therefore the disc is kept in place with an external ring (3) (see Fig. 1). This ring not only presses slightly the composite disc onto the steel disc at the edge, but also makes sure that the composite disc stays centered to the rotation, yielding a perfectly circular wear pattern on the disc. This replaceable disc construction is then placed on a fixed disc (4). The whole disc construction rests on two bearings, and is driven by the axis