WEAR MECHANISMS OF PULTRUDED GFR COMPOSITE PLATES

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Abstracts

Classical wear and friction experiments on a Pin on Disc - with composite disc - yield the formation of a thin film at the composite wear track, as a result of particles, falling from the edges of the wear track, being pressed against and later on over the composite surface, depending on the normal force and the underlying composite structure. This thin film deforms continuously, resulting in larger and darker wear particles at the edges of the wear track. Another mechanism for the building up of this thin film is that due to the shear forces in the film under the pin top that the underlying structure 'wears' and results in different characteristic wear mechanisms. This thin film yields a reduction of the frictional force with almost 20%. After the 'removal' of the film as a result of the structure the friction force reaches is old level. Related to the production method, the results of the fibre orientation on the friction force can be shown. Perpendicular fibre orientation yields higher frictional force, parallel results in a lower friction force.

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1. INTRODUCTION

The study of wear 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 these as components for use in actual service requires good understanding of the processing related structure and its influence on wear and friction. 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 [5]. A friction process is always accompanied by the development of wear debris, which adheres to the rubbing couple [6,7,8]. As a result, a characteristic friction layer (thin film) forms on the surface, and this thin film determines performance [9].

Keeping this aspect in mind, the response to dry sliding wear of glass–polyester has been looked into. After wear runs the mating surface of the composite is recorded using scanning electron microscope (SEM) [10], and also the cross section of the resulting wear track is recorded with SEM.

2. MATERIALS AND METHOD

2.1: Test Rig

Due to the importance of online monitoring, a new pin-on-disc test rig (Figure 1) was built in order to be able to monitor online the behaviour of composite materials as bearing material. In this new test set up a high speed camera (1) to visualize the wear state of the composite disc online will be used. This means that the most common set up [11-15] (composite pin/steel disc) cannot be used for these online measurements. In that way, pin and disc were changed, resulting in a composite disc and a steel pin. The wear track, as a result of the pin on disc test can now be online visualised by a camera.

The pin is constructed to contain most of the additional sensors (acoustic emission [16,17], 3D accelerometer [17-19], strain gauges and thermo couples). The pin of length 35mm is hollow at the top, to use strain gauges, for the measuring of possible bending of the pin. Two flat parallel faces very near the contacting surface are places for the accelerometer and the acoustic emission sensor. Thermo couples can be placed all over the pin geometry. The mating surface, or the bottom of pin, is a ball, from a ball bearing (∅8 mm), which can be replaced to get a multiple use of the pins.

Resulting characteristics of this test rig are: speeds from 10 till 100 mm/s, a possible normal load up to 1000N, an online camera (1) and the possibility to place sensors on the pin (2). For the measuring of the depth of the wear track, a contact less proximitor (3) is used, which will give a relative indication of the wear depth.

For the measuring of the normal force on the pin a load cell is placed above the pin (4). This load cell is protected by a mechanism that allows pressing directly on the load cell, without damaging this load cell. Another method to measure the normal force on the pin is by measuring the air pressure in the cylinder (5).

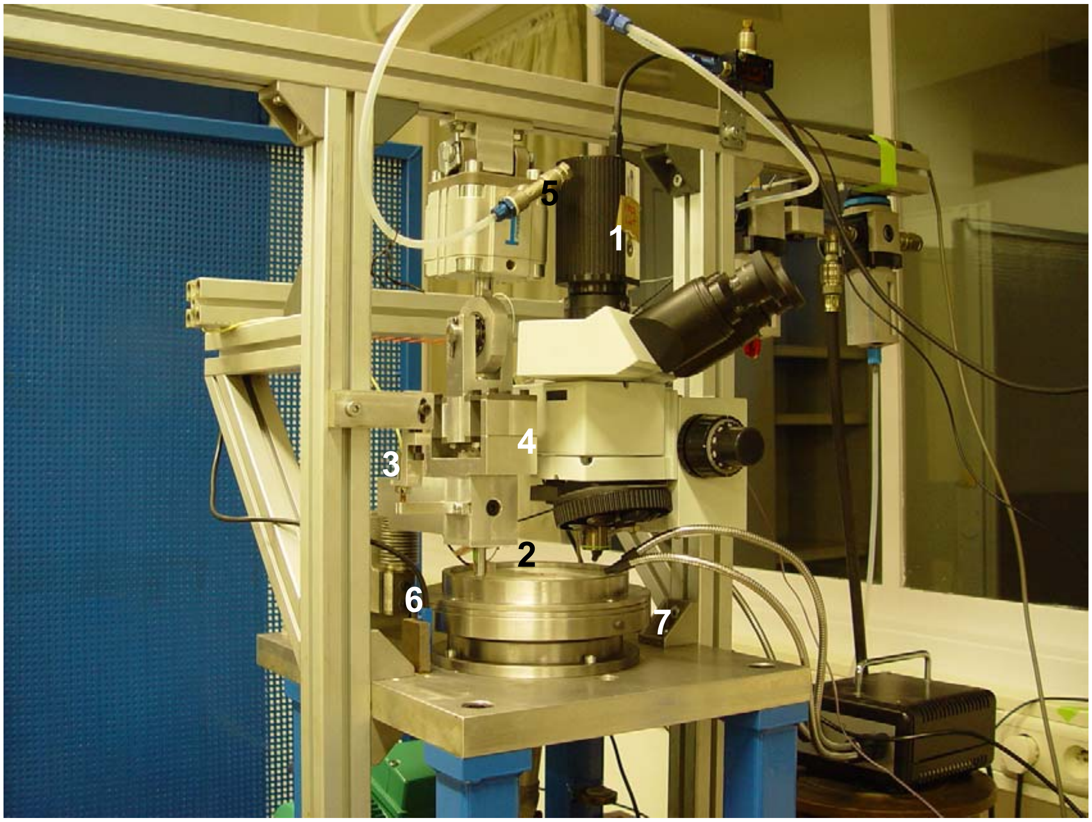


Figure 1: Pin on disc test rig

The normal force can be put on the pin via two different mechanisms. The first is via an air pressure cylinder (5), the other method is via a death weight (not on figure). The friction force is measured with a load cell (6) based on bending.
On the rotating disc magnets (7) are placed, which are needed to indicate the fiber orientation in the discs, and are also used as triggering for various signals.
On a steel disc (1), the composite disc is fixed with bee wax. Due to high loads this might not be enough and therefore the disc is kept in place with an external ring (2). This ring not only presses slightly the composite disc onto the steel disc at the edge, but also prohibits this composite disc to leave the center of the disc, yielding a circular wear pattern on the disc.

2.2. Material and fabrication of test specimens
The material used was a pultruded composite profile with flame retardant low profile polyester without halogens as a matrix, and as reinforcement glass fibers (50 weight%, ±5%)[20-23] (Exel Composites NV). The structure of the material can be seen in Figure 2, A. This material is build up of several layers, with a roving at the top and the bottom of the profile and a continuous mat in the middle. The total thickness of this profile is 3mm.
The final test specimens [24], the composite discs, with a fixed diameter of 160mm were cut out of the pultruded profiles via water jet. In order to indicate the fiber orientation in the bulk after cutting the discs, two lines were brought onto the composite profile in the length of the fibers before cutting). Each disc has thus a line on one side, indicating the fiber orientation of the continuous fibers. Due to the cutting of different samples out of the same plate, a constant quality of the specimens can be guaranteed. Tests were performed on the side without the marks.

The pin is made of 42CrMo-steel, and the final contact is a ball-bearing steel grade (hardness 63 HRC, composition: C = 1.03%, Si = 0.25%, Mn = 0.35%, Cr 1.4%), with diameter of 8 mm within narrow tolerances and roughness, which was fixed into the pin with two components glue.

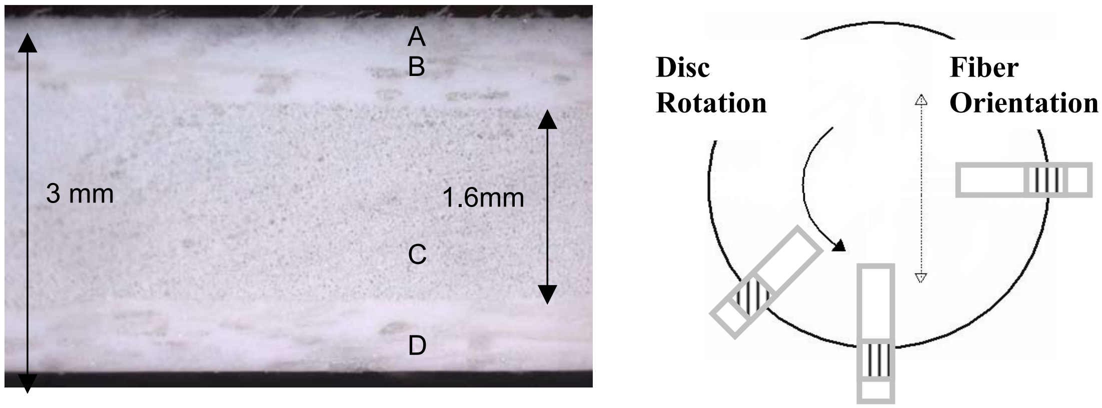


Figure 2: **A**: Transverse section of the composite material, with A a surface mat, B and D the non-woven and C the zone with unidirectional fibres, **B**: Scheme for cutting out the test specimens for further SEM research

For the SEM studies, the composite discs were cut into pieces with a diamond saw, following the profile like in Figure 2, B. The test specimens were numbered (see Table 1) and the samples with corresponding fiber orientation were kept in original form, respectively cleaned with acetone, without rubbing.

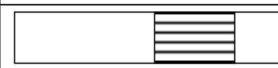
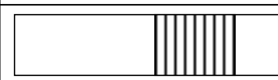
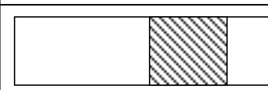
Monster number	**Fiber orientation**	**Treatment**	**Fiber orientation**
	Related to the direction of movement	Original or cleaned	
M1	90°	Original	
M3	90°	Cleaned	
M2	0°	Cleaned	
M4	0°	Original	
M5	45°	Original	
M6	45°	Cleaned	

Table 1: Numbering and properties of test samples for SEM

3. RESULTS

A characteristic result of the friction is presented in Figure 3. This figure gives the evolution of the friction force of the steel – composite pair over time, for a normal load of 240N and a speed of 10 mm/s. The total sliding time of 400.000s is the result of 10.000 rounds of 400mm each, witch yield a total sliding distance for the pin of 4km. In this graph there are several regions to be determined.
During running in of pin and disc, a clear rise in friction force is obtained. This is due to the material structure, a top layer of polyester, reinforced with polyester fibers, and

due to the rise in contact area between pin and disc. After the running-in period the friction force decreases. This is due to a larger contact area.

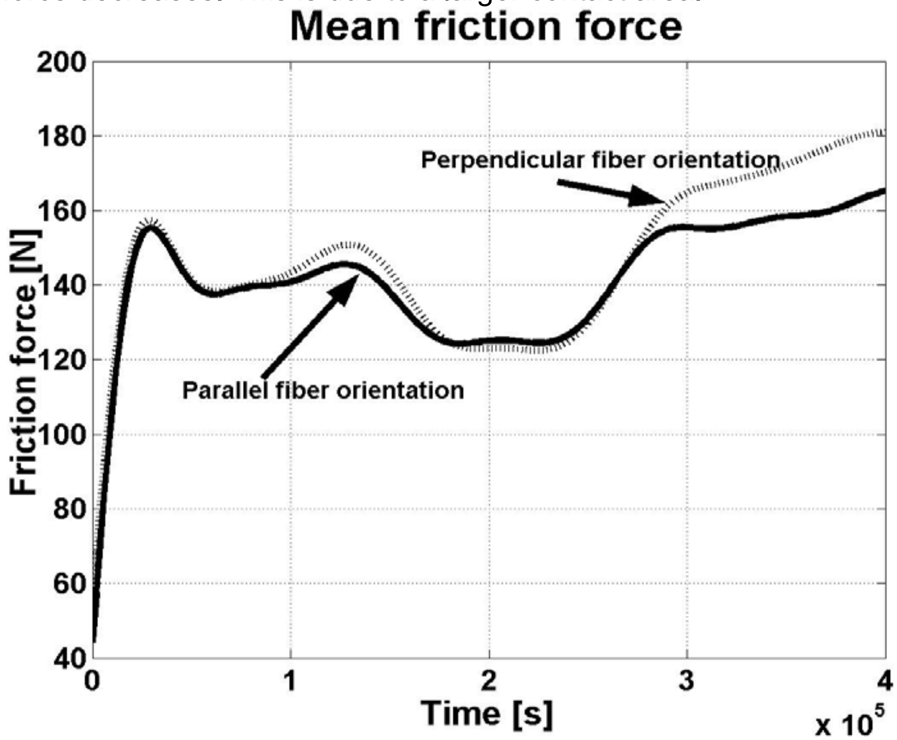


Figure 3: Friction force at different angels

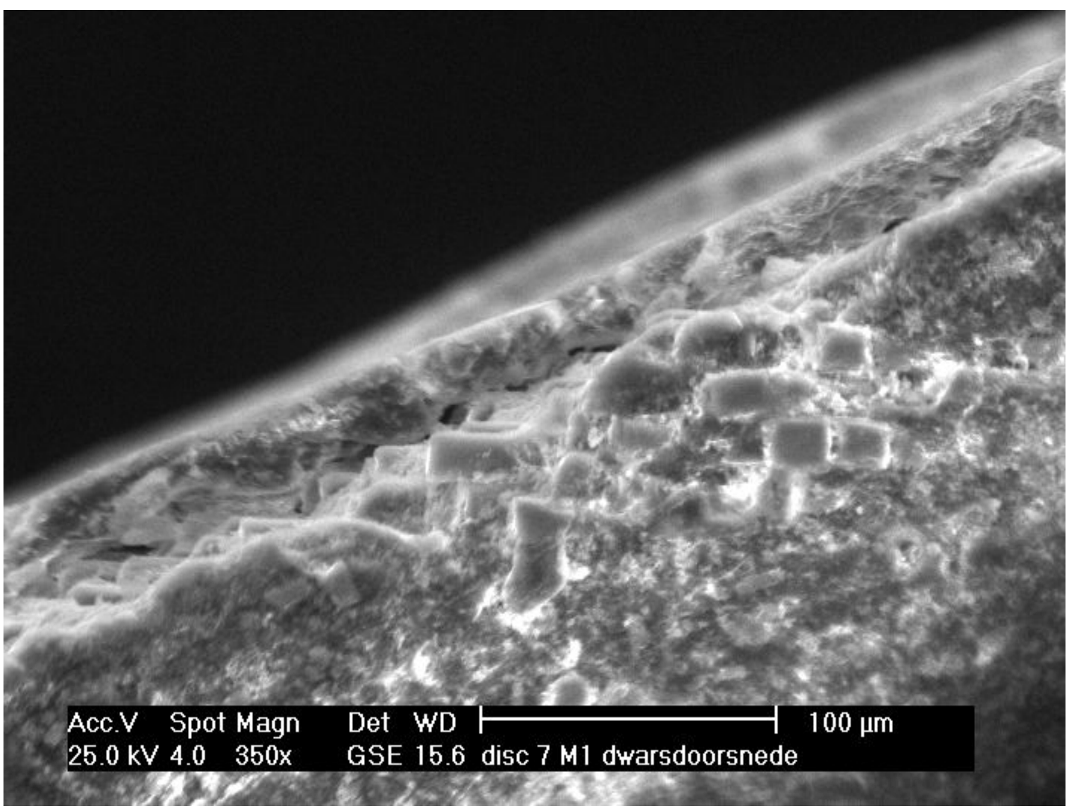


Figure 4: Cross section with clear view on the thin film (120N, 10mm/s)

After 15.000s the friction force is lowered with 20%. The formation of a thin film in the wear track can be visualized (Figure 4). Finally after some 27.000s a split up in friction force, depending on the fiber orientation can be seen. Also the rise of the friction force, witch might be due to a stiffer contact, and the removal of the thin polymer film. These findings are further supplemented by the surface features as seen in SEM photomicrographs (Figure 4) taken at several regions of the worn surface, and by analyzing the wear rate of the composite specimen.
Figure 5 shows the corresponding wear evolution of the same test as in Figure 3. This graph represents the total wear depth of the pin and disc combination. A higher wear rate at the start of the test run is observed, and then a lowering of the wear rate, due to a lowering in contact pressure (larger contact area) and material structure.

This graph (Figure 5) indicates the differences in wear rate, due to change in contact geometry, material structure and the development of a thin polymer film in the wear track.
The formation of a thin polymer film in the wear track of the composite specimen is the result of several mechanisms. First of all, as a result of a wider track, related to the wear of these composites particles are always pressed aside the wear track. When the wear track grows (becomes wider and deeper), the particles need to make place for the pin. Most of these particles will move at the top surface of the disc, but some of them will be taken by the pin and end up in the wear track, under the pin. Looking at the final result of the disc validates this statement. Wear particles, with different colors (from pure white till nearly black) can be found on both sides of the wear track, with the white ones the most far from the track due to earlier remomval.
Secondly, also the underlying surface provides material for this film. Indicated by a rise in wear.

Typical wear mechanisms of polymer matrix composites are: fiber breaking, fiber-matrix debonding, matrix cracking [2,24]. These mechanisms are supported with SEM micrographs. If looked at Figure 6, although there was the protection of a thin polymer film, shear of the fiber (P), and for that reason breaking of the fiber and its removal is observed. Also fiber matrix debonding (Q) and matrix fracture (R) are detected. The Figure 7 reveals the following mechanisms. Fiber matrix debonding (P), fiber breaking and removal (Q), pealing of the matrix (R) and fiber fracture (S).
Figure 8 is a top view of the wear track, but more near the edge. The mechanisms that are visible here are fiber matrix debonding (R), brittle fracture of glass fibers and wear of the matrix material as a result of the movement of the fibers (P, Q). The direction of movement of the pin is from bottom to top, vertical. This means that the broken fibers are, each time the pin passes, pushed forwards and after passing the fiber returns to its original place. This results in a matrix removal due to the pressure induced by the moving fiber (P). The other void visible in Figure 8 is the result of the pressure induced by the bending of the fiber in the horizontal plane of contact. These wear is not due to load and speed, but only induced by the movement of fibers, which of course is the result of the sliding of the pin.

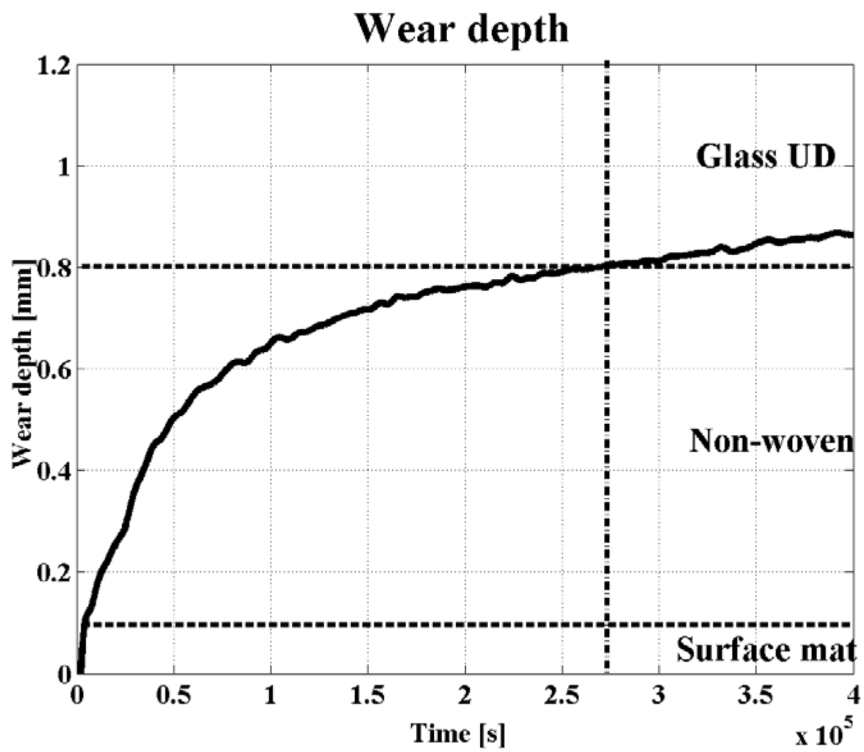


Figure 5: Wear evolution at 240 N and 10 mm/s, with indication of the structure of the material

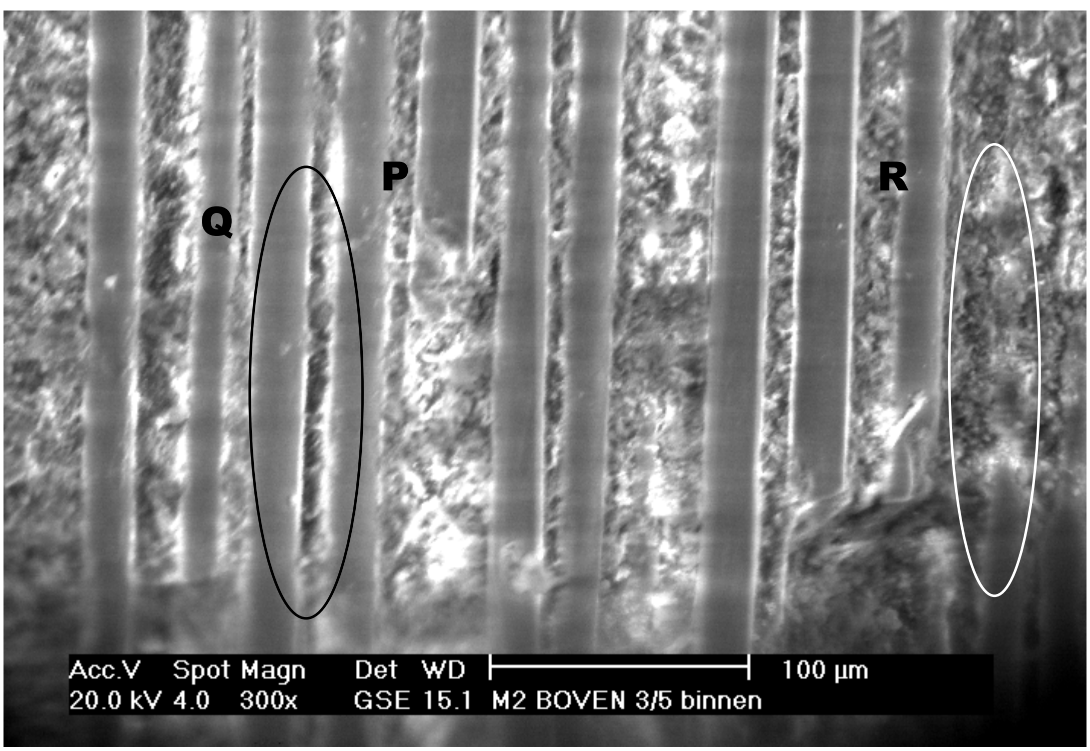


Figure 6: Wear track, fibre orientation parallel to sliding direction

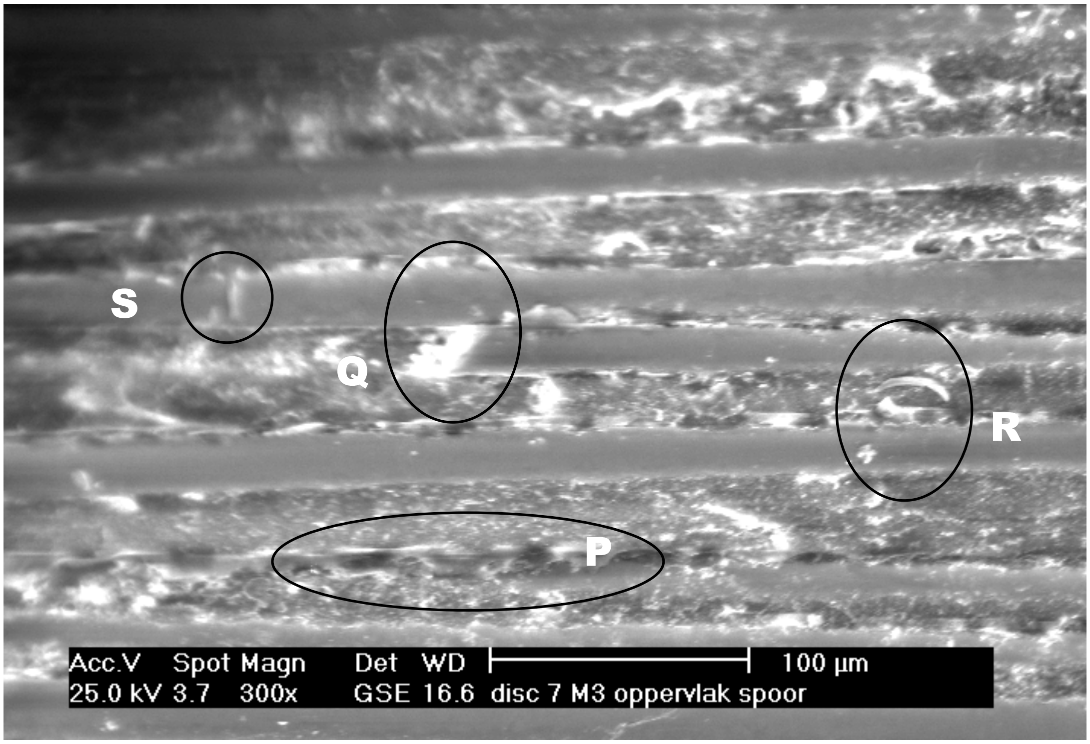


Figure 7: Wear track, fibre orientation perpendicular to sliding direction

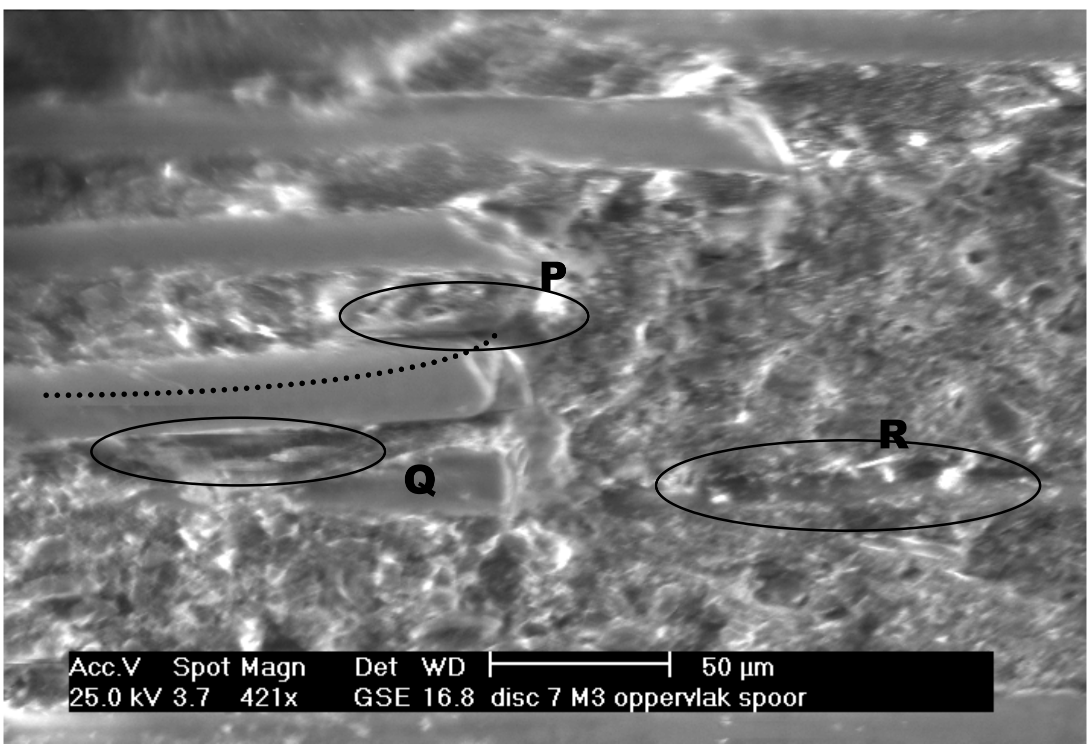


Figure 8: Top view of the wear track, indicating several wear mechanisms, fiber matrix debonding, fibre fracture, matrix removal due to movement of fibers

4. CONCLUSIONS

Based on the experimental observations, and SEM micrographs, the following conclusions can be drawn.

1. The friction force is dependent on the formation of a thin polymer film on the wear surface. The friction force also depends on the orientation of the fibers. Parallel orientation results in lower friction, transverse in a higher friction.
2. The thin film does not protect the underlying surface, with a typical wear behavior as result.
3. The wear mechanisms are well indicated with the SEM micrographs. Although there is a difference in test-setup with literature, all these mechanisms are taken place.
4. The influence of fibers as reinforcement on the wear leads to a fiber related wear track. The fibers determine the final curvature of the wear track. These fibers also induce another type of wear. They are responsible for a typical wear mechanism, as a result of bending of fibers.

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