NEW TEST-SETUP FOR ONLINE MONITORING OF WEAR MECHANISMS OF POLYMER MATRIX COMPOSITES

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SUMMARY

The Laboratory Soete developed a new test setup, based on the well-known pin-on-disc test rig. Instead of the standard composite specimen and steel disc, a rotating composite disc and a steel pin is used to be able to have a visible wear track. Standard wear and friction measurements will be further combined with acoustic emission measurements, infrared thermography and vibration measurements. A high-speed camera will be used to acquire digital images of the worn composite surface. These online measurements are used to see the evolution in damage gradually.
The combination of all these measurements should yield valuable information on the active wear mechanisms, the occurrence of fibre and matrix fracture, fibre pull out, generated frictional heat, formation mechanisms of wear particles, and the interaction between al these effects.

1. INTRODUCTION

The study of wear of polymers in general and polymer based composites in particular is finding increasing citations in literature due to the availability of wider choice of materials, ease of manufacturing, good strength, and light weight. An area in which their use has been found to be very effective are the situations involving sliding contact wear. The polymer-based materials are preferred in recent years over metal-based counterparts in view of their low coefficient of friction [1] and ability to sustain high loads. This has given an impetus to industrial production of the materials, as for instance in the production of composite bearing components used in automobile industries such as gears, cams, wheels, etc. The introduction of fibres as reinforcing agents in polyester based polymer materials widen the scope for structural application in view of their processing useful properties like tensile strength in the range, flexural modulus in the range in addition to light weight (density kg/m^3). However, the deployment of these materials as components for use in actual service requires good understanding of the processing related structure and its influence on wear.
Techniques for wear analysis are acoustic emission [2], particle analysis, SEM, … Most of these techniques are post mortem analysing techniques. Due to differences between the static and kinetic coefficient of friction, restarting a tribological test means changing the original parameters of the material, resulting in differences in wear behaviour of the two materials.
In this paper we will focus on online wear monitoring of polymer matrix composites, creating a new test setup to make online monitoring possible.

2. TEST SET UP

Online wear monitoring of composites needs to result in finding correlations between signals measured online and the wear mechanisms occurring at the same time. Therefore this new test set up will use an online camera to visualize the wear state of the composite disc online. This means that the classical set up (composite pin/steel disc) cannot be used for these online measurements. 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. Thus possible lose of fibres, the occurrence of fibre and matrix fracture, fibre pull-out, etc. should be visualised online. The resulting test set up is given in figure 1A, more detailed information about the pin in figure 1B. The final resulting characteristics are given in Table 1.

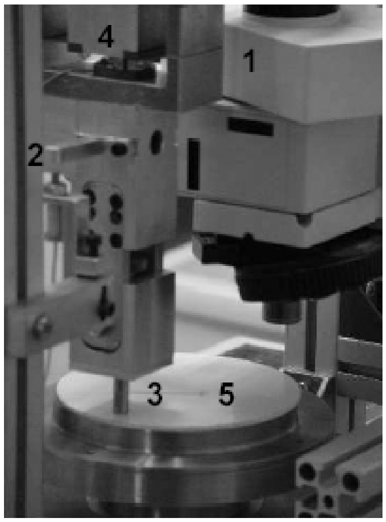


Figure 1A: Test area with: 1: Microscope, 2: Bentley contactless distance sensor, 3: Pin 4: Vertical loadcell 5: Rotating Composite disc

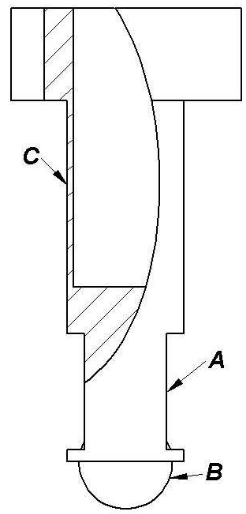


Figure 1B: Construction of the pin

The pin is constructed to contain most of the additional sensors (acoustic emission, 3D accelerometer, strain gauges, thermo couples), resulting in a pin as shown in figure 1B. The pin is hollow at the top, because after a first test, it was impossible to measure anything with the strain gauges (C), which were placed on the outside of the hollow part of the pin. The two flat faces (A) 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 contacting surface in this figure is a ball (B), and to get always the same geometry it is a ball from a ball bearing (∅8 mm).

Table 1: Final characteristics

<table>
<tr><td>Speed</td><td>10 mm/s to 100 mm/s</td></tr>
<tr><td>Test Specimens</td><td>Disc of ∅160 mm with thickness of 3 mm</td></tr>
<tr><td>Maximum friction force</td><td>500 N (max. capacity of the loadcell)</td></tr>
<tr><td>Normal load</td><td>Up to 1000 N</td></tr>
<tr><td colspan="2">Online camera</td></tr>
<tr><td rowspan="4">Sensors</td><td>Thermo couples</td></tr>
<tr><td>Accelerometer (3D)</td></tr>
<tr><td>Strain gauges</td></tr>
<tr><td>Acoustic Emission</td></tr>
<tr><td>Wear depth</td><td>Up to 1600 mm</td></tr>
</table>

3. PRELIMINARY RESULTS

3.1. Material

The material used is a polyester grade, reinforced with glass fibres. The plate was pultruded, indicating a constant fibre orientation. The pultruded profile exists of 3 layers: a surfacing mat (~ 0.1 mm), a continuous mat (~ 0.6 mm) and continuous glass fibres (~ 0.8 mm), and symmetrical again continuous fibres, a continuous mat and a surfacing mat, resulting in a disc thickness of 3mm. The discs were cut out via water jet from a pultruded plate.

3.2. Preliminary results

Wear measurements

Classical wear measurements, due to material removal of the composite disc, resulting in a wear track, but also in a lowering of the arm carrying the normal load. Total wear of about 500 µm, resulting not only from wear but also due to some deformation of the disc. This results in a classical wear curve, without immediate indication of the presence of fibres in the material. The normal force is about 62 N.
Each point is the result of an average of 250 points measured at 50 Hz.

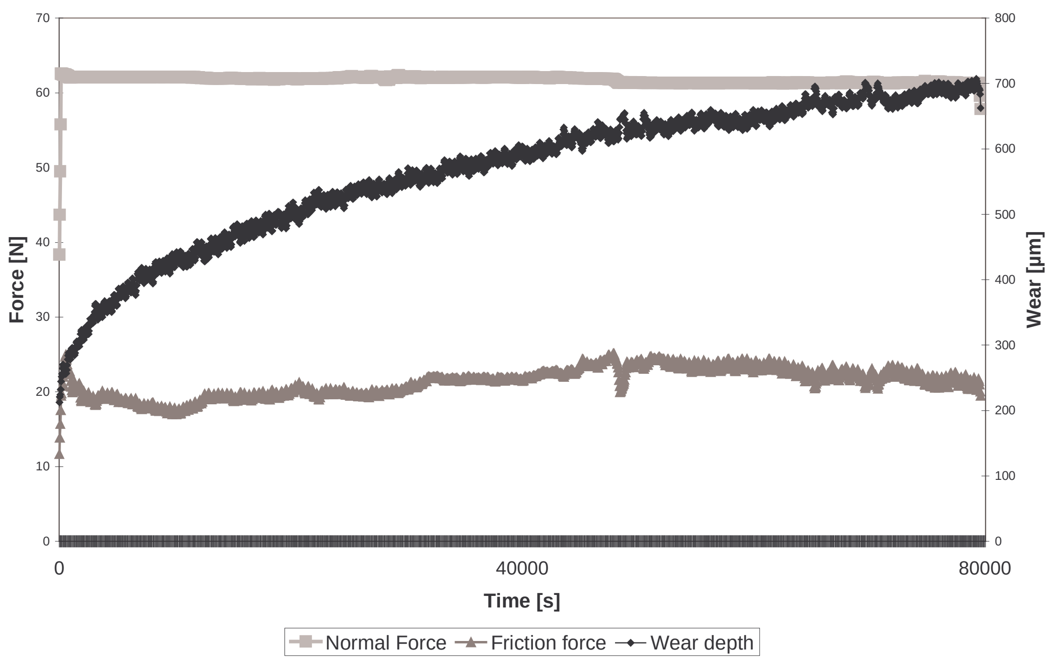


Figure 2: Complete test

Continuous rounds

Not only the overall wear and friction was measured, but also the evolution during a full round. Information from these rounds gives an indication of the state of the wear track during that round. The result of two continuous rounds is illustrated in figure 3. Between those two graphs are 50 rounds. The normal load is the light line above, indicating a constant normal load of 62 N, with no variation during one round. The line beneath this represents the wear, indicating a high-low difference of almost 200 µm, for round 550 and for round 600 as well. The lowest line is the friction force. The influence of this force gives an indication of the surface roughness of the wear track. If both friction forces are compared, and keeping in mind that the measured time was not perfectly one round, a great correlation between these two graphs can be observed. The first peak (~0.5) is a little wider in the second graph. This might be due to the loss of a particle creating a bigger crater at the surface of the wear track. An identical profile can also be seen between 2.5 and 4. The global profile between these two, in the knowledge that there were 50 rounds between them, indicates not much variation in the surface during this period. The measured vertical displacement also does not give any global difference.

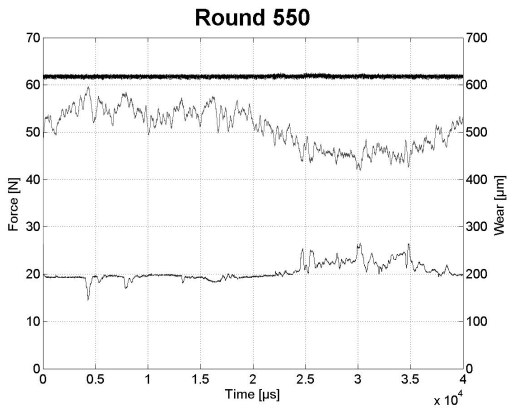


Figure 3A: Round 550

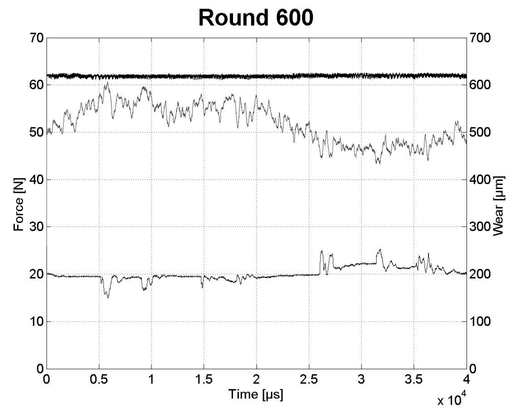
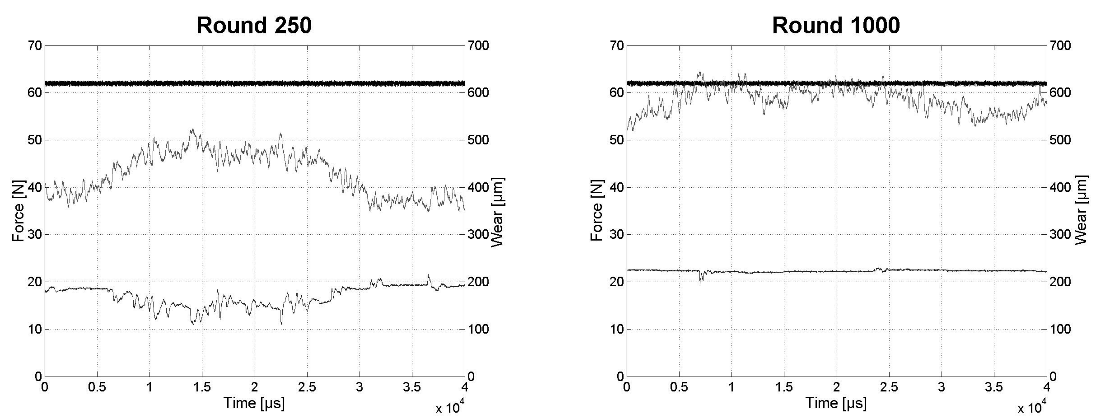


Figure 3B: Round 600

If the results of the whole tests are compared, see figure 4, indicating that there is an evolution of the friction force as function of time. In round 1000 the profile for a complete round is almost completely constant, which might be an indication that at that time there were no fibres in the contact zone. This leads to a possible conclusion that the surfacing mat is worn away. Later on, the profile of the friction force changes again, and a profile of the whole disc becomes visible.



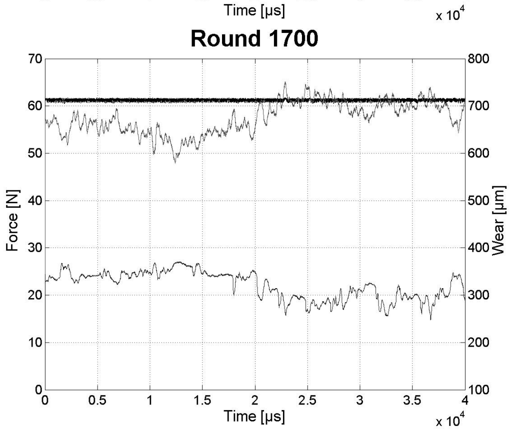


Figure 4: Left up: Round 250, Up: Round 1000, Left under: Round 1700

Interesting to see is the strong correlation between the friction force and the wear during one continuous round (round 250 and 1700) although not always (round 1000).

Vibration measurement

The influence of vibrations can be seen in figure 5A. Due to high friction forces and a lack of pretension, the geared belt is raised above the pulley and jumps one pitch forward. This resulted in a total reduction of the friction force, even a negative friction force, a resulting vibration measured with the vertical displacement sensor, and measured with an accelerometer. The results can be seen in figures 5B and 5C. The results indicate that both the vertical displacement sensor and the accelerometer measured the same signal in the same manner, although the accelerometer had noticed the 'vibration' a little bit earlier.

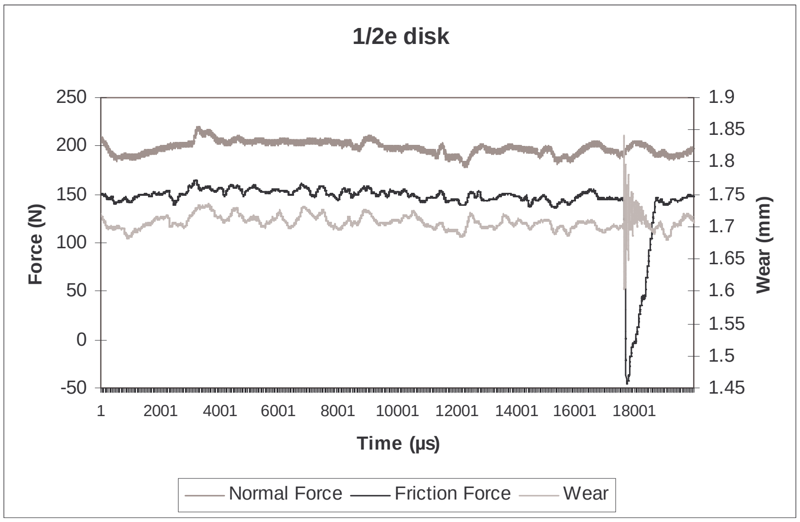


Figure 5A: Influence of the geared belt skipping one pitch

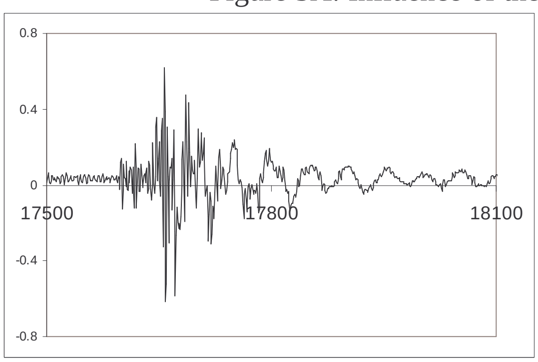


Figure 5B: Vibration measurement

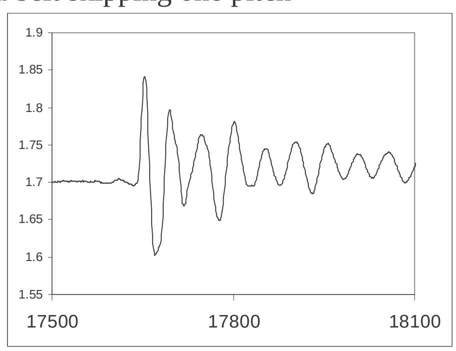


Figure 5C: Wear response

Image processing

In order to visualise the wear track online, and also to be able to prove the previous stated results, an online camera was placed on the test rig, as can be seen in figure, 1A. This camera will be used to give information about two things. First of all, it will be needed to explain results measured with the other sensors (AE, Accelerometer, Friction Force, …). On the other hand, it will be used to visualise possible changes in particle sizes, during the test.
As a first step the influence of focus on the resulting image is studied. As can be seen in figure 6 (A-D), none of these figures give a perfect result, although these are real pictures. The resulting image (figure 6E) gives the result after some image processing. Of all the above pictures, one global image is created.

The resulting image still has a large black zone. This is the result of only one light source, which creates shadows of particles, and cannot lighten the whole area of the image. The global altitude of the resulting image is 360 µm, and the resulting image is created out of 36 pictures with a constant difference of 10 µm.
These images are taken offline, meaning the disc was not turning at the time.

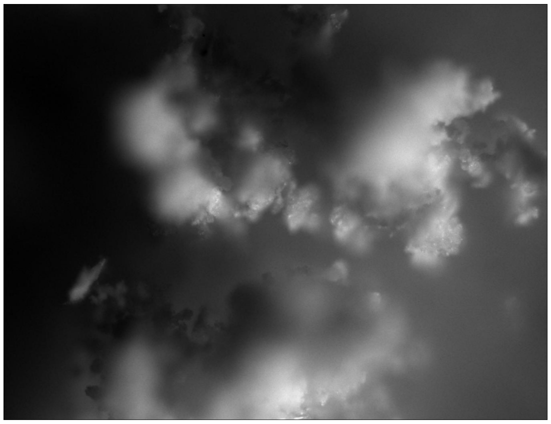


Figure 6A

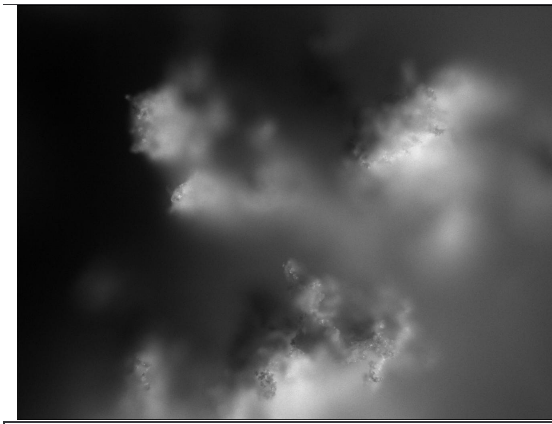


Figure 6B

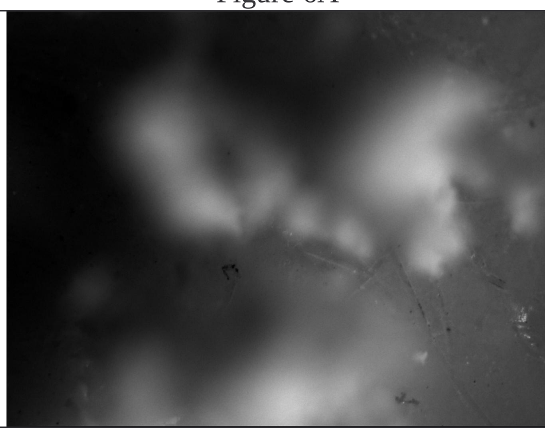


Figure 6C

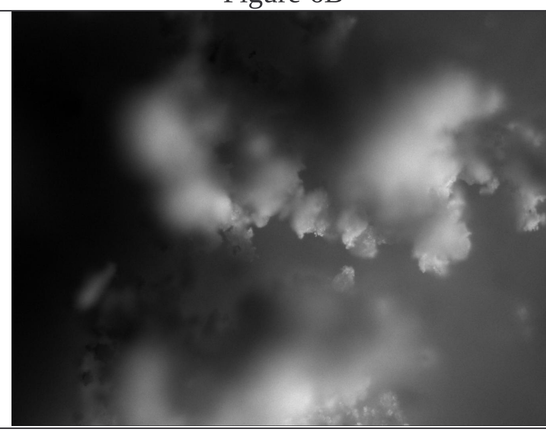


Figure 6D

Figure 6E: Resulting image

The dynamic pictures are still experimental and not automated. The problems here are getting enough light, the short opening time of the camera (till 40 µs) and due to a colour camera, the influence of the colour components on the resulting image. The image in figure 7, indicating some first results of removal of particles, is the result after some basic photo operations (greyscale, brightness).

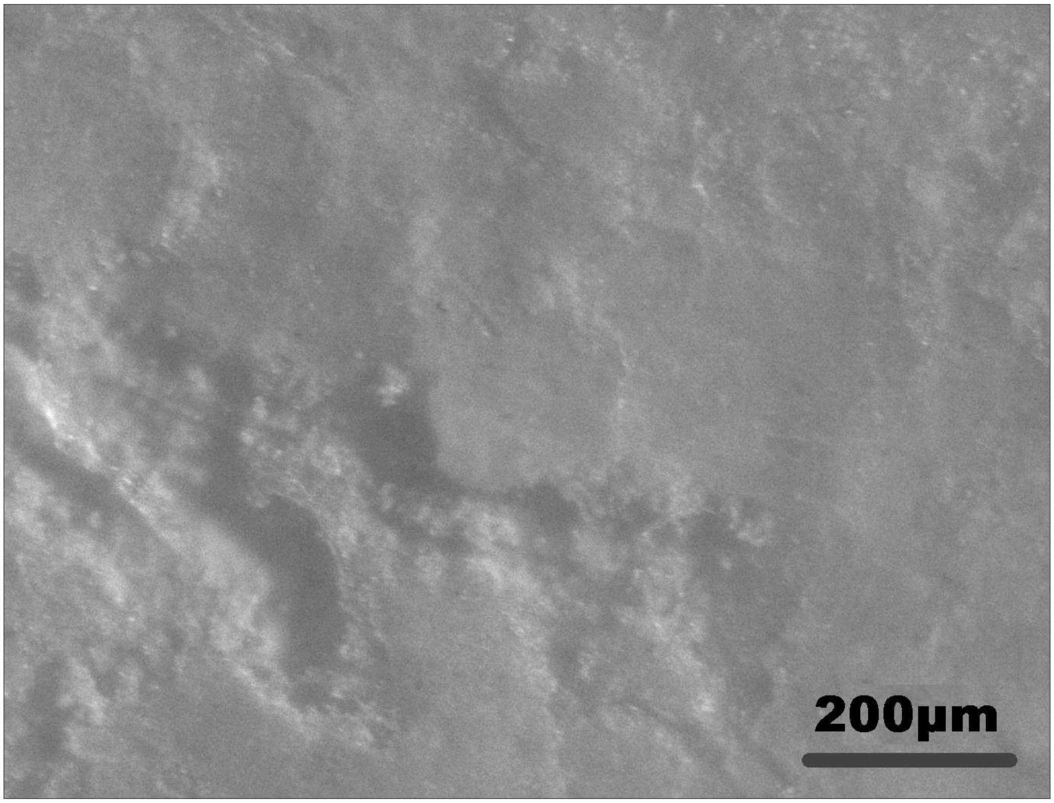


Figure 7: The wear track

4. CONCLUSIONS

- A new test setup is available and gives some interesting results
- Due to measurements of continuous rounds, extra information can be reached about the current state of the surface.
- The construction of the layers of the disc follows from the continuous round results.
- Image processing leads to clear pictures, but cannot be done online.
- The results of dynamic images are still rare.

5. REFERENCES

[1] Biswas S.K., Vijayan K.:Friction and wear of PTFE_a review; Wear Vol. 158, 1992

[2] Huguet S., Godin N., Gaertner R., Salmon L., Villard D.: Use of acoustic emission to identify damage modes in glass fibre reinforced polyester; Composites Science and Technology, Vol. 62 (2002), 1433-1444