Influence of material structure properties on sliding contact performance of CGRP composite

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ABSTRACT

In the current work, an experimental investigations on friction and interface temperature of chopped strand mat glass fibre (type-R) reinforced polyester (CGRP) sliding against smooth stainless steel are presented. Pin-on-disk (POD) apparatus was used to perform the experimental tests under dry contact condition. Several tribo-parameters are considered, namely load (30, 60 & 90N), sliding velocity (2.8, 3.52 & 3.9m/s) and sliding distance (0-2.51km). In addition, the CGRP composite was investigated in two different orientations of chopped strand mat (CSM) glass fibre in the matrix, with respect to sliding direction and counterface, i.e. Parallel (P) and Anti-parallel (AP). Friction forces and interface temperatures were measured simultaneously. To observe the damages feature on the worn surface of CGRP composite, scanning electron microscopy (SEM) is used. The results of friction coefficient and interface temperature were presented as function of sliding distance at different loads, velocities and orientations. Experimental results revealed that orientations of CSM glass fibres and test parameters played a major role in friction and interface temperature behaviour. Tested parameters (load, sliding distance, sliding velocity and orientations of CSM glass fibre in matrix) have an essential influence on the friction coefficient and interface temperature results of the CGRP composite. AP-orientation produced high friction coefficient (0.5-0.6) and interface temperature (29-50^{o}C) in compared to P-orientation. High damage on the CGRP surface were found when the CGRP tested in AP-orientations at higher load and velocity, i.e. fibre break, peels off, debonding, polyester deformation.

1. INTRODUCTION

Fibre reinforced polymer composites are currently became widely used due to their superior properties gained by low density and cost. Numerous applications of polymeric composites found their ways in automotive and aerospace industries products, e.g. gears, seals, bushes, and cams [1,2]. Tribological studies on such composites attract many engineering designers due to the fact that 90% of the failure in designed parts are caused by tribological environment [1, 3,4]. Therefore, many attempts have been made to improve the tribological characteristics of them by using reinforcement materials, e.g. fibres and filler. In fact, some of tribological properties of polymer could be improved significantly by the incorporation of fibre reinforcement [5,6] and some time worsened them [1,3]. However, comprehensive study on tribological characteristics of such composite is highly recommended.

Glass fibre reinforced polyester (GFRP) is one of the common used composites due to their advantages, i.e. light, low cost, easy to manufacture, high strength and high resistance to the environment. In tribological point of view, there are some reported works have been carried out to study the effect of glass fibre on tribo-performance of the thermoset polyester resin [1-5,7,8].

Abrasive wear behaviour of GFRP composite has been studied in three body mode by N. Chand et al [7]. In that work, the size of abrasive particles and applied load have increased the wear rate; meanwhile increase sliding velocity have contributed to reduce the wear rate. In the same time, higher weight fraction of randomly distributed glass fibres improved the wear resistance of the composite. This was due to the higher energy required to facilitate failure in glass fibres. In another work, participant authors [3] studied the abrasive wear behaviour of chopped strand mat (CSM) glass fibre reinforced polyester (CGRP) composite in multi-pass abrasive wear mode considering three different orientations of CSM with respect to the sliding direction and counterface. It has been found that the orientations of CSM glass fibre had significant influence on the abrasive wear results of CGRP composite. As a result of that work, high abrasive wear rate was evident when the composite were tested in normal orientation (N-O), where the CSM was oriented parallel to the sliding direction and counterface. This was because of the rubbing mechanics in N-O, i.e. either layer of polyester was subjected to sliding against the

counterface or glass fibre mat. This weakened the exposed layer of the composite leading to delaminate, debonding, break and cut the fibres.
Meanwhile, Anti-parallel orientation showed lower wear rate, since less damage was noticed on the worn surface of the composite in that orientation, i.e. matrix debris transformation into the glass region led to reduce the wear rate.
There are few studies were reported on the tribological behaviour of GFRP composite against smooth stainless steel [1, 5]. H. Pihatili and N Tosum [5] have investigated the CGRP composite in one orientation (N-O) using block on ring (BOR) machine at different applied load and sliding distance. As results, in spite of the high damage have been found on the worn surface of CGRP composite (removal of polyester and fibres), the adhesive wear resistant of composite was high in compared to the neat polyester (NP). In that work, it has been mentioned that high weight loss was taken place due to high interface temperature. Participant authors found that the wear rate of the CGRP composite in N-orientation was very high in compare to P and AP-orientations in abrasive [3] and adhesive tests [1].
From the previous studies, [1-8], it can be concluded that there is less attention was paid to understand the effect of test parameters and CSM orientations on interface temperature. While, interface temperature is another equally important parameter that controlling friction and wear behaviour of CGRP composite [9-11]. This motivates the participant authors to report the current work on the effect of test parameters and CSM orientations on friction coefficient and interface temperature of CGRP/SS at different applied load (30-100), sliding velocity (2.8-3.9) and sliding distance (0-2.5km). Friction coefficient and interface temperature were measured simultaneously and the results presented as function of sliding distance.

2. EXPERIMENTAL DETAILS

2.1 Preparation of Tested Materials

Chopped strand mat (CSM) R-glass fibre 450 g/m^2 was selected as reinforcement and unsaturated polyester as a thermosetting resin. Chopped Strand Mat (CSM) is a comprised sheet of randomly dispersed chopped fibres held together. The current CSM contains 20-30 mm fibre length and 450g/m^2 mass of fibres. The orthophalic unsaturated polyester (Revesol P9509) pre-promoted for ambient temperature cured with addition of Methyl Ethyl Ketone Peroxide (MEKP) as catalyst. Reinforcement and polyester materials were supplied by Kong Tat Company of glass fibre engineering (Malaysia). A hand-lay up technique was adapted to fabricate the polymeric composite. Detail information about the selected materials and its fabrication processes were given somewhere else [1,3]. Chopped strand mat glass fibres reinforced polyester (CGRP) composite were built up to 15 mm thickness, containing 13 layers of CSM glass fibres and the thickness of the polyester interlayer about 66.25μm. The CGRP composite specimens of size 11mm x 11mm x 15mm were machined from a plate of size 250mm x 250mm x 15mm and the sliding was performed on 11 x 11mm^2 face. The CGRP specimen's orientations with respect to sliding direction are shown in Fig.1.

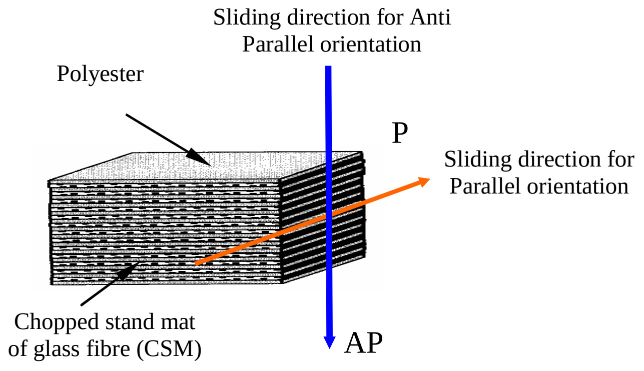


Fig. 1- Schematic illustration of CGRP specimens showing the orientations with respect to sliding direction

2.2 EXPERIMENTAL EQUIPMENTS

A previously designed and fabricated pin-on-disc POD tribo-test machine [1] as shown schematically in Fig..2 was used for the present experiments. The disc was made of smooth stainless steel (AISI 304) of 170mm diameter and 6 mm thick. It was grinded and polished using abrasive paper (Diamond Brand Water Proof, No.120) to a surface roughness of 0.09 μm Ra.

Dry sliding tests were conducted at room conditions of temperature (24^{o}C) and humidity with different normal loads (30, 60 and 90 N), sliding velocities (2.8, 3.52, and 3.9 m/s), and sliding distances (0-2.5km). The sliding tests were conducted for two different orientations of CSM with respect to the sliding direction, i.e. Parallel (P) and Anti-Parallel (AP). Before each test, the composite specimen was rubbed over a SiC abrasive paper 166-grade to ensure proper intimate contact between the rotating counterface and the specimen, i.e. uniform contact. Simultaneous measurements of friction force and interface temperature were carried out during the tests, the frictional forces were measured using load cell (± 0.75N) that mounted on the load lever as shown in Fig. 2. Each specimen was tested at least three times at same conditions, and friction coefficients were calculated. The interface temperatures were measured by using infrared thermometers (SUMMIT SIR 10B, ± 0.5 ^{0}C). The thermometer was pointed to the midpoint of interface between the specimen and the stainless steel counterface. The thermometer position was kept fixed during the test procedure. Scanning electron microscopy SEM (JEOL, JSM 840) was performed on worn surfaces to observe the damage features. Before taking the micrographs, the worn surfaces were coated with a thin layer of gold using ion sputtering (JEOL, JFC-1600).

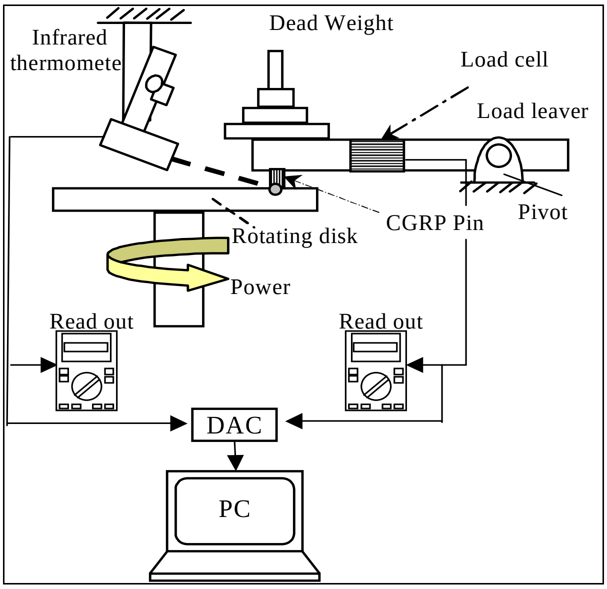


Fig. 2- Layout of the experimental set-up for measuring the friction and interface temperature

3. RESULTS AND DISCUSSION

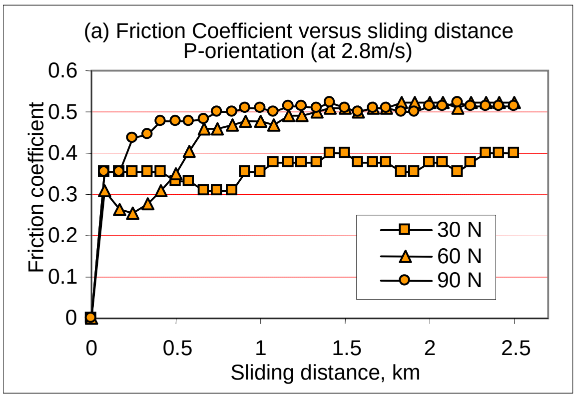
Experimental tests were performed to investigate friction coefficient and interface temperature of CGRP composite sliding against polished stainless steel counterface at different applied load (30, 60 and 90N), sliding distance (0-2.5km), sliding velocity (2.8, 3.5 and 3.9m/s) and two different principle orientations of chopped strand mat glass fibre in the matrix. Friction coefficient and interface temperature results are presented against sliding distance at all tested parameters for the two orientations.

3.1 Effect of applied load

The results of friction coefficient and interface temperature of CGRP/SS at different applied load (30, 60 and 90N) and 2.8m/s sliding velocity are presented in Figs. 3-8 for two different orientations (P and AP).

Fig. 3 a and b show the variation in the friction coefficient and interface temperature of CGRP when it was tested in P-orientation at different applied loads. In general, low friction coefficient and interface temperature is presented at low applied load. Increase the applied load contributes to increase the interface temperature, while the friction coefficient is the same for both high loads. After 0.7km sliding distance, steady state of the friction coefficient could be noticed. Meanwhile, the interface temperatures at all applied loads are increased gradually when the sliding distance increased due to the heat generated by the friction. The effect of the sliding process on topography of CGRP surface in P-orientations are shown in Fig. 4 a and b at 30 and 60N applied load respectively. The layers of CSM glass fibre and polyester are parallel to the sliding direction. At low load 30N, Fig. 4a shows that some polyester desires are deformed and covered the fibrous region. In the same time, some of the fibre ends are exposed to the rubbing process. In contrast, Fig. 4b shows high deformation in the resinous region is taken place and polyester debris worn away. Moreover, fibres ends are highly exposed to the rubbing against stainless steel counterface, Fig. 4b, in compared to lower load 30N, Fig. 4a. When less fibre is transferred from to the resinous region that could lead to reduce the thrust force producing lower friction, Fig.3. Meanwhile, at higher load, consequently, the ends of the fibres are strongly exposed to the counterface surface causing bending in fibre, peel off and higher damage as apparently seen in Fig4b. This leads to increase the resistance of CGRP composite generating higher high fiction, Fig.3a. Higher deformation in the polyester resin and some crakes may be observed that due to the higher temperature generated by the friction during the rubbing process at higher load. After 2.5km sliding distance, maximum friction coefficient and interface temperature are evidence at higher load (90N), which is about 0.5 and 45^{o}C.

As for CGRP composite in AP-orientation, Fig. 5a shows scattered values of friction coefficient. In the same time, steady state of friction coefficient is not developed in short sliding distance, since it is reached the steady state after 2km approximately. Furthermore, at all applied loads, increase the sliding distance shows increase the friction coefficient and no remarkable differences on the effect of the applied load on the friction coefficient are noticed. Maximum value of friction coefficient is found to be about 0.6 at 60N load and longer sliding distance 2.5 km. The higher friction coefficient could be taken place due to the rubbing process of the CGRP in AP-orientation, i.e. fibres in CSM were against the sliding direction. Therefore, transformation of fibres and polyester debris from/to other regions are highly noticeable at low and high load as shown in SEM images, Fig. 6.



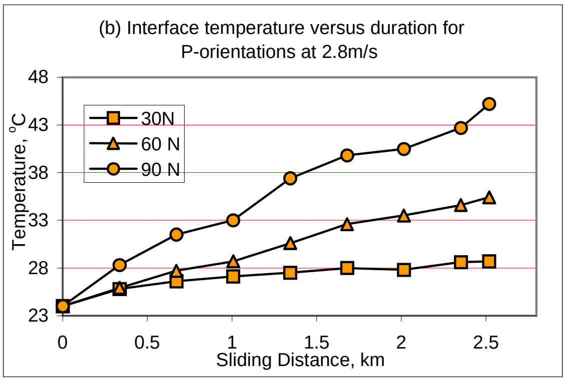
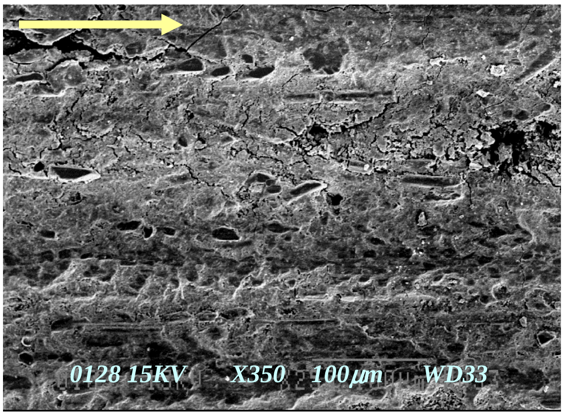
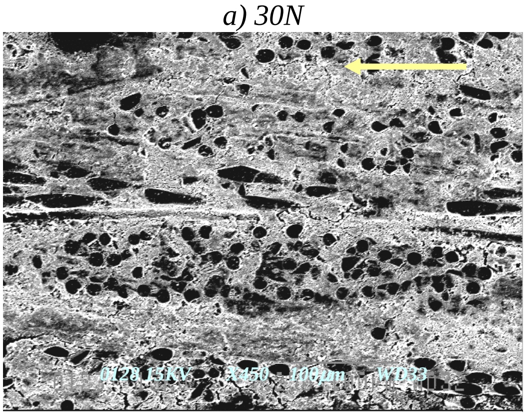


Fig. 3- Friction coefficient and interface temperature of CGRP sliding Vs sliding distance showing the effect of applied load in P-orientation at 2.8 m/s

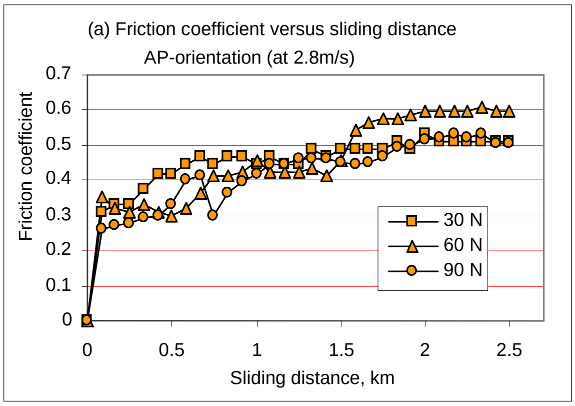


a) 30N



b) 60N

Fig. 4-SEM photographs of worn surface for different loads at P-orientation, 2.8m/s and 2 km.



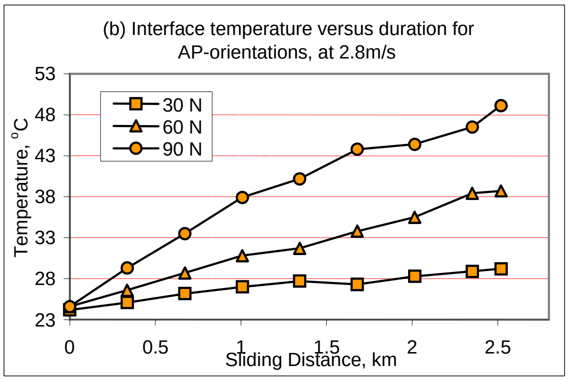
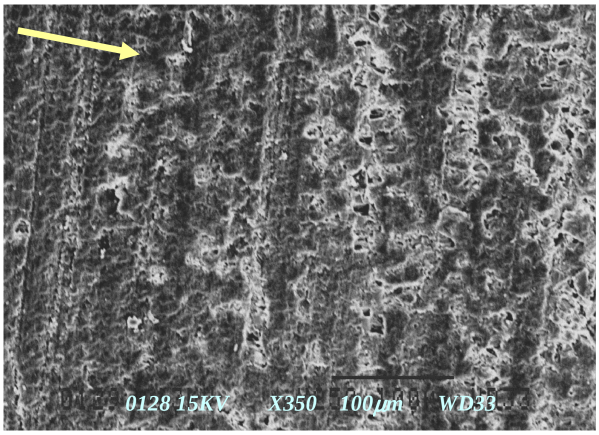
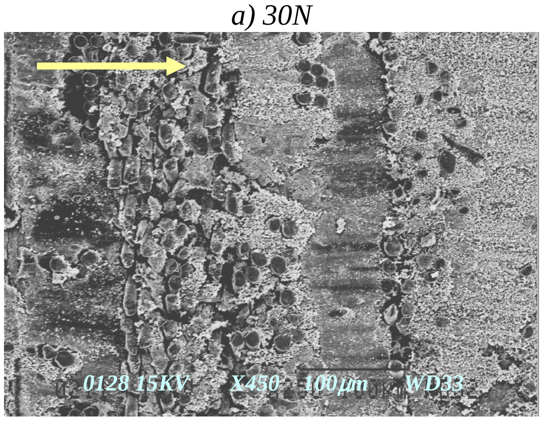


Fig. 5- Friction coefficient and interface temperature of CGRP sliding Vs sliding distance showing the effect of applied load in AP-orientation at 2.8 m/s



a) 30N



b)60N

Fig. 6-SEM photographs of worn surface for different loads at AP-orientation, 2.8m/s and 2.5 km

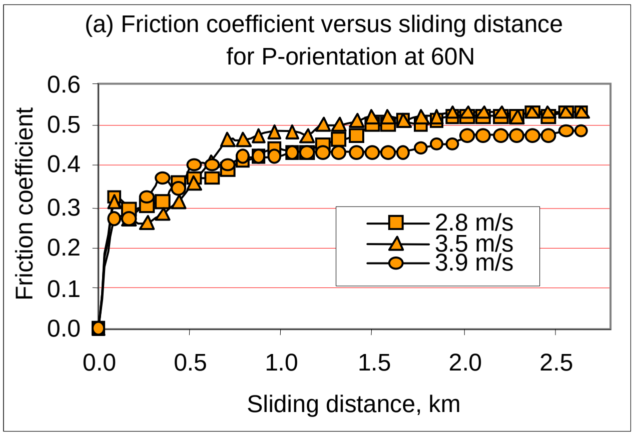
Moreover, at low load 30N, CSM glass fibre is almost covered by polyester deformed debris Fig. 6a. Meanwhile, at higher load 60N, it can be noticed that most of the deformed polyester debris are worn away and CSM glass fibres are almost resist the sliding against the counterface alone, i.e. rubbing process is taking place between CSM glass fibre against the counterface. This may increase the resistance in the rubbing zone leading to high friction coefficient, Fig. 5a.

The variation of the interface temperatures of CGRP/SS in AP-orientation are seemed to be elevated gradually when the sliding distance increased, Fig. 5b. Moreover, at the lower load (30N), there is no significant impact of sliding distance on the interface temperature. Furthermore, increase the applied loads causes a significant increase in the interface temperature. Maximum value is about 50^{o}C at 2.5 km and 90N.

3.2 Effect of Sliding Velocity

The effects of the sliding velocity on the friction coefficient and the interface temperature are presented in Figs. 7-10 at 60N applied load for P and AP orientations of CGRP composite. Fig. 9a shows the measured friction coefficient of CGRP as function of sliding distance in P-orientation at different sliding velocities 2.8, 3.5 and 3.9m/s. it can be seen that, at all sliding velocities, the friction coefficient is reached the steady state after 0.7km. Further, higher sliding velocity 3.9m/s shows lower friction coefficient in compared to low and intermediate velocities, which show almost the same values.

Fig. 7b shows that the interface temperatures at higher velocities (3.5 and 3.9m/s) are almost the same, i.e. there is no much effect of velocity on the interface temperature at tested condition. This may due to the heat dissipated to the environment via convection process at high velocities of the counterface. The convection of the heat from the counterface was difficult to determine. However, further investigation on this part is recommended. Lower interface temperature seems to be at low sliding velocity 2.8m/s. The effect of increase the sliding velocity on the CGRP surface are shown in SEM images at 2.8 and 3.9 m/s sliding velocity, Fig. 4b and Fig.10 respectively. In comparing both Figs., it can be observed that the damages on worn surface at higher velocity 3.9m/s is seemed to be higher than lower velocity 2.8m/s, since some of the fibres are peeled off, end cut, bended and removed. The similarity in the friction coefficient at high sliding velocities could be due to the high temperature at that condition which developed a thick polyester film on the counterface. In that case, the sliding is taking place on polymer against polymers this lead to reduce the friction coefficient as noticed at high velocity 3.9m/s.



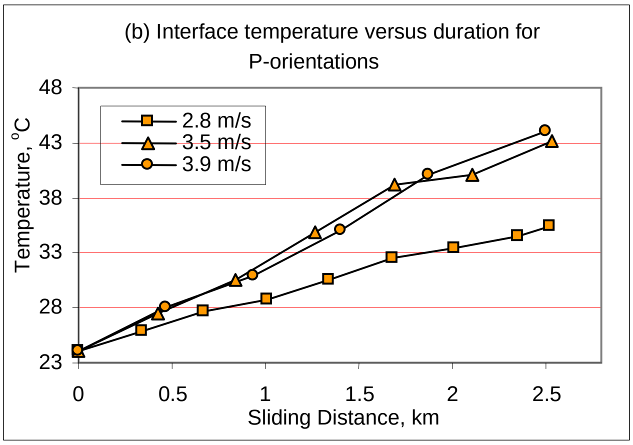


Fig. 7- Friction coefficient and interface temperature of CGRP sliding Vs sliding distance showing the effect of sliding velocity P-orientation at 60N applied load

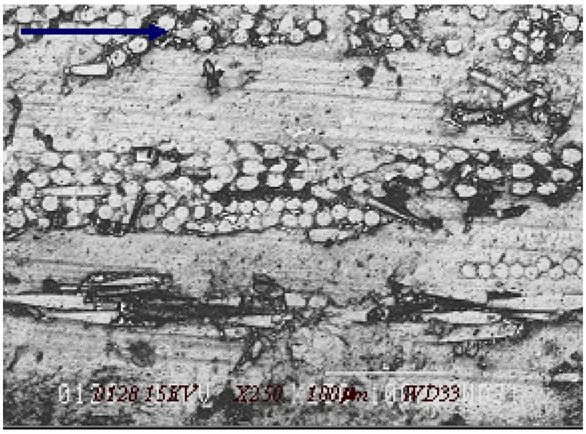


Fig. 8-SEM photographs of worn surface of CGRP in P-orientation at 3.9m/s for 2.5km

The effects of the sliding velocity on the friction coefficient of CGRP composite tested in AP-orientation is found to be scattered as shown in Fig. 9a. At all tested sliding velocities, the steady state are noticed after 2km. Higher friction coefficient is seemed to be at intermediate velocity 3.5m/s, which is about 0.6. Regarding the effect of sliding velocity on the interface temperature of CGRP composite tested in AP-orientation, Fig. 9b, it is turned to be similar to the P-orientation results, i.e. there are no differences on the interface temperature when the sliding velocities increased from 3.5m/s to 3.9m/s. Meanwhile, lower sliding velocity produces lower interface temperature.

The increasing in the sliding velocities shows higher damage to the worn surface when the CGRP was tested in AP-orientation at 3.9m/s as observed on the SEM images, Fig. 10. Deformed and removed polyester debris are observed between the CSM glass fibre layers indicating that the deformed debris were worn away. Furthermore, there is no transfer of polyester debris to the fibrous region and the damages in the fibrous region are categorized by fibre break, peel off, debonding.

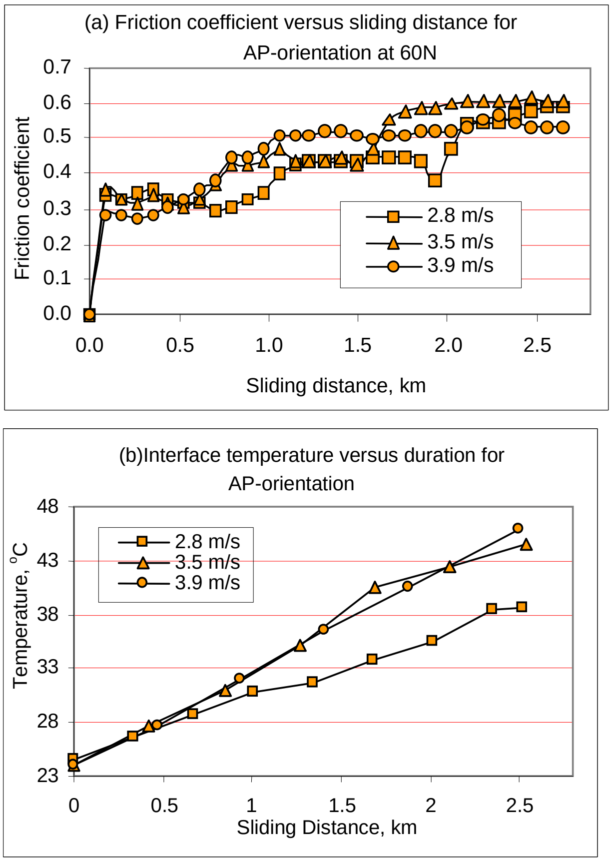


Fig. 9- Friction coefficient and interface temperature of CGRP sliding Vs sliding distance showing the effect of sliding velocity AP-orientation at 60N applied load

Finally, to show the effect of the CGRP orientations (P and AP) on the friction coefficient and interface temperature, some of the above results are extracted and plotted in Fig. 11 a and b at 2.8m/s sliding velocity and 60N applied load. From the Fig., P-orientations shows lower friction coefficient and interface temperature in compared to AP-orientation at tested conditions. This is due to the different in the rubbing mechanism of CGRP composite in different orientations, i.e. when the CGRP composite tested in AP-orientation the CSM glass fibre layers were perpendicular to the sliding direction. This causes higher resistance leads to high friction coefficient and interface temperature combined with higher damages on the exposed surface of the CGRP in that orientation, Fig.6.

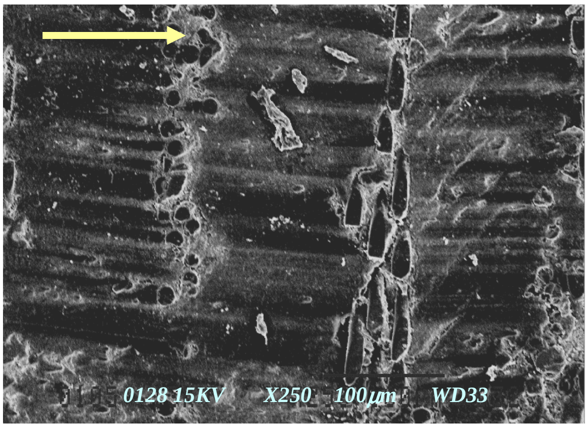


Fig. 10 SEM photographs of worn surface of CGRP in AP-orientation at 3.9m/s for 2.5 km

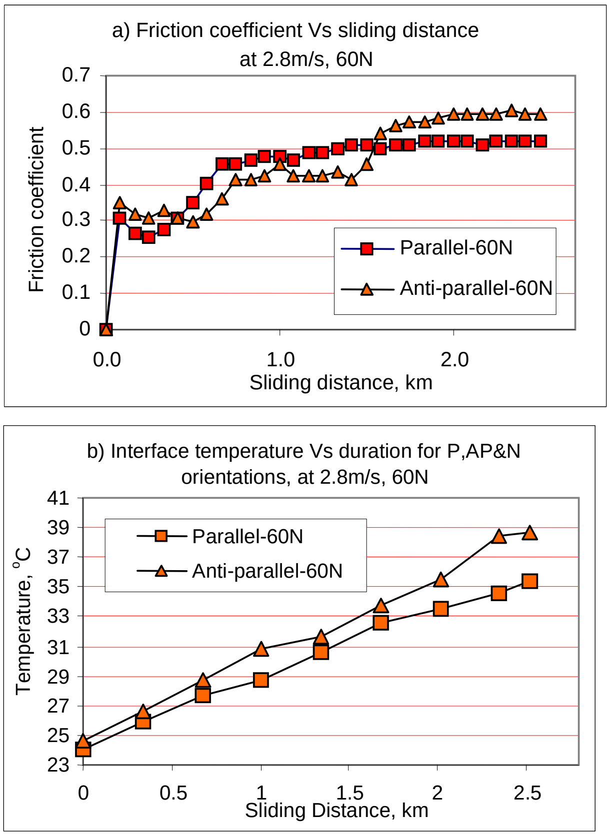


Fig. 11 Friction coefficient and interface temperature of CGRP at 2.8m/s sliding velocity and 60N applied load for both P and AP-orientations

4. CONCLUSION

After carrying out the investigations on the friction coefficient and interface temperature of CGRP composite sliding against stainless steel counterface, the resultant work can be concluded as follow:

1. Tested parameters (load, sliding distance, sliding velocity and orientations of CSM glass fibre in matrix) have an essential influence on the friction coefficient and interface temperature results of the CGRP composite.
2. An increase in the applied load or/and the sliding distance is proportional with the interface temperature for two orientations.
3. AP-orientation produced high friction coefficient (0.5-0.6) and interface temperature (29-50^{o}C) in compared to P-orientation, which was about (0.4-0.5) friction coefficient and (28-45^{o}C) interface temperature.
4. The damages on the CGRP surface were strongly depended on the tested parameters and CSM glass fibre orientation in the matrix. High damages in the resinous and fibrous regions were observed when the CGRP tested in AP-orientations at higher load and velocity, i.e. fibre break, peel off, debonding, polyester deformation.

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