REPLACING OF GLASS FIBRES WITH SEED OIL PALM FIBRES FOR TRIBO-POLYMERIC COMPOSITES[1]

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ABSTRACT

In the current study, the possibility of replacing woven glass fibres (WGFs) with seed oil palm fibres (S-OPFs) as reinforcements for tribo-polymeric composites is investigated. Mainly, two different polyester composites based on woven glass reinforced polyester (WGRP) and seed oil palm reinforced polyester (S-OPRP) are developed. Different volume fractions (25, 35, and 45Vol. %) of seed oil palm fibres were considered. The experiments were performed using a Block-on-Disk (BOD) machine and the tests were conducted under dry contact condition against smooth stainless steel counterface at 2.8m/s sliding velocity, 20N applied load for different sliding distances (up to 5km). The wear mechanism was categorized using an optical microscope. The results revealed that the steady state was reached after 4km sliding distance for both WGRP and S-OPRP composites. S-OPRP composites showed very high friction coefficient compared to WGRP. However, S-OPRP composite with 35Vol. % exhibited a promising wear result, i.e. S-OPFs are possible to replace WGFs in polymeric composites reinforcements whereas the wear resistance of the synthetic and natural composite were almost the same. The wear mechanisms for S-OPRP composites were pre-dominated by micro-cracks, deformation and pulled-out of fibres while in the WGRP composite, abrasive nature was observed.

Keywords: Glass fibres, Seed oil palm fibres, replacing, wear, friction.

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1. INTRODUCTION

Tribological performance of polymeric composites reinforced with synthetic fibres such as glass, carbon and Kevlar, have been extensively studied by many tribologists. Recently, there has been a growing concern with regard to the increase in the rate of depletion of petroleum resources. However, new environmental regulations have been raised, forcing material designers to find substitutes for synthetic fibres that should be compatible with the environment. Natural fibres exemplify environmentally friendly alternatives to conventional reinforcement fibres, as they present numerous advantages over synthetics ones. For instance, they are: obtained from abundantly available renewable resources; non-toxic; bio-degradable, low in cost, flexible in usage, high in specific strength and low in density [1-11]. These advantages and the current environmental issues render natural fibres attractive as reinforcement materials for polymers. Natural fibre-reinforced polymeric composites are found in many products such as housing construction materials, furniture and automotives parts. On the other hand, the introduction of natural fibres as reinforcement to tribo-polymeric composites has not been comprehensively considered. In other words, there is a lack of understanding concerning the impacts of natural fibres on the tribological performance of polymeric composites.

A study of the effect of natural fibres on tribo-polymeric composites was carried out by El-Sayed [12] who explored linen and jute fibre-reinforced polyester composites in dry adhesive wear mode at different volume fractions of fibres. In that work, the volume fraction of the fibres was found to control the wear and friction properties. Moreover, a 33 vol.% fraction of fibre enhanced the wear properties and worsened the friction. During the wear process, stray fibres were bent and directed to the sliding direction without being pulled out from the matrix. This assisted in protecting the polyester region thus leading to a reduction in the material removal. In another attempt, the effect of jute fibres on the abrasive wear behaviour of polyester composites was studied [13]. In that work, the influence of the addition of a maleic anhydride-grafted polypropylene coupling agent on the abrasive wear performance of the composite in two body abrasive wear mode against a 400 grade abrasive paper in multi-pass condition was determined. The results demonstrated that the use of a coupling agent gave rise to an improved wear resistance as compared to other cases. The formation of linkages at the interface between the matrix and the jute fibres during deformation played a significant role in the wear process. In other words, interfacial adhesion between the fibres and the matrix controlled the wear performance of jute-polyester composites. In a recent study by Hashmi [14], the adhesive wear performance of graphite modified polyester–cotton composites using Pin-on-Disc against steel under dry contact conditions was reported. Incorporating cotton fibres in the polyester resin improved the structural integrity of the material, and addition of graphite in the cotton–polyester composites further enhanced the capability of the material to withstand sliding wear. Cotton fibres reduced the specific wear rate of the polyester, however, it increased the friction coefficient. The latter was significantly reduced with the addition of graphite in the cotton–polyester composite. In another study by the same authors [15], ultrahigh molecular weight polyethylene (UHMWPE) modified polyester-cotton composites were investigated with respect to dry adhesive wear at various UHMWPE concentrations. The specific wear rate of the polyester composite decreased when it was reinforced with cotton and UHMWPE. Meanwhile, the friction coefficient increased with addition of cotton and was significantly reduced with the inclusion of the combination of UHMWPE and cotton. A content of 7.41 vol.% was found to be the optimum volume fraction, at which the composites exhibited high reductions in specific wear rate. For the friction coefficient, 14.19 vol.% UHMWPE in a polyester resin reduced the friction coefficient to nearly half of that in the neat polyester, and to approximately 1/3 of that in a cotton polyester composite.

The participant author studied the tribo-performance of polyester composite based on coir fibres and promising results were recorded [16]. However, it is found an interest to study the second type of fibres which are in the seed of the oil palm fruit. From the palm oil factories, it is found that the deposit fibres came from the oil palm seed are equivalent to the one come from the bunch. In the current work, friction and wear performance of polyester composites based on seed oil palm fibres and glass fibres in woven form is investigated at different operating parameters against smooth stainless steel using newly developed block-on-disc machine. The main application of the current materials is for bearings.

2. EXPERIMENTAL DETAILS

2.1 Fibres and composites preparation

Two different types of fibres, woven glass fibres (WGFs) and seed oil palm (S-OPFs), were used as reinforcements for unsaturated polyester. Both WGFs and unsaturated polyester were supplied by Kong Tat Company of glass fibre engineering (Malaysia). The S-OPFs were prepared locally. An oil palm fruit bunch was obtained from the local farms in Melaka city, Malaysia. In the fibre preparation process, the fruit in the bunch were crashed into small pieces and then washed. The fine fibres were extracted from the fruit and washed to remove undesirables. The prepared fibres were dried under room temperature (24^{o}C) for 24 hours. Finally, the fibres were cut into length of 1-2cm.

Both WGRP and S-OPRP composites were fabricated by using hand-lay up technique. For fabricating the WGRP composites, the unsaturated polyester was first pre-promoted to room temperature and then cured with MEKP (catalyst). A thin layer of liquid polyvinyl acetate (PVA) was applied as a release agent on a smooth wooden mould. A paint roller was soaked into unsaturated polyester and rolled over the bottom surface of the mould to make the first layer of unsaturated polyester. Then a layer of WGF was laid over the first layer of unsaturated polyester.

For seed oil palm fibres reinforced polyester (S-OPRP) composites, a similar method of WGRP composite was implemented. The S-OPFs were oriented randomly in the mould and pressed into a mat (15mm thickness). The unsaturated polyester was then poured into the mould and the S-OPRP block was cured at room temperature for 24hr. While building up the S-OPRP composites, three different types of composites based on volume fraction (25, 35 and 45%) were fabricated by putting corresponding amount of fibres into the mould. A neat polyester (NP) was simply fabricated by using unsaturated polyester without any reinforcement material. All the composites were machined into specimens in size of 10 mm x 10 mm x 20 mm.

2.2 Principles of tribo-machine

The friction and wear tests were carried out using block-on-disk (BOD) a tribo-machine having a stainless steel counterface. Fig. 1 shows the newly developed BOD machine. The load cell is responsive to the friction between the specimen and counterface which would be presented in unit kg by friction indicator. The thermometer transmits the infrared radiation to the contact of two surfaces and indicates the interface temperature by receiving the reflected radiation.

El-Sayed (1996) determined the higher PV limit of polyester, which was 1.61 MPa m s^{-1}. Accordingly, the PV was selected as 0.56 MPa m s^{-1} for the current work. The experiment was conducted at 20N of applied normal load (equivalent to at 0.2MPa) at 2.8 m/s sliding velocity for different sliding distance (up to 5km)".

The counterface surface was first polished by using silicon carbide paper (1500 grade) to clean the contamination. The composite surface was polished using silicon carbide paper (1500 grade) to ensure a fully contact of two surfaces. The weights of the specimens were measured and recorded as initial weights. Both friction and interface temperature was recorded every 0.17km. Meanwhile, the weight of the specimen was measured and recorded every 0.84km. The procedures were repeated for different type of the composites.

Each test was repeated at least three times at same condition and the average of the results were determined. Typical values of the standard variation of the specific wear rate are listed in table 1. The worn surfaces of the composite were coated with a thin layer of gold using an ion sputtering device (JEOL, JFC-1600) to observe the microstructure of the composite using SEM (JEOL, JSM 840).

Table 1. Typical values of the standard variation of specific wear rate.

Material	standard variation
NP	0.25 to 1.98
S-OPRP 25%	0.13 to 0.87
S-OPRP 35%	0.15 to 1.2
S-OPRP 45%	0.12 to 1.35
WGRP	0.14 to 1.1

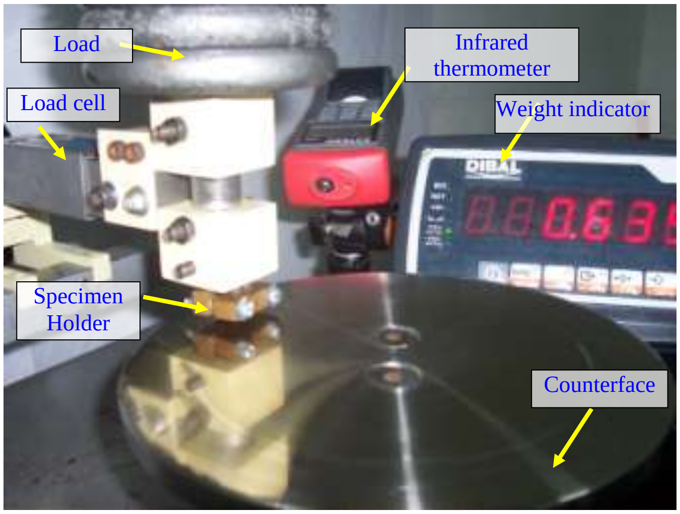


Fig. 1 Newly Developed Block-on-Disc (BOD) tribo-machine.

3. RESULTS AND DISCUSSIONS

3.1 Effect of sliding distance on wear

Fig. 2 shows the specific wear rate of NP, and S-OPRP and WGRP composites as function of sliding distance. At the beginning, all the composites show different specific wear rates. However, the sliding distance increases, the composites tend to reach stable specific wear rates after 4km sliding distance, i.e. reached the steady state. Obviously, neat polyester and S-OPRP composites (with 25 and 45Vol. %) experienced relatively high specific wear rate compared to WGRP and 35 Vol.% S-OPRP. The lower range of the specific wear rate for WGRP and 35 Vol.% S-OPRP composites are approximately 3 to 8x10^{-5}mm^3/Nm. The WGF and 35 Vol.% S-OPF have significantly improved the adhesive wear performance of neat polyester. Moreover, it indicates the capability of 35Vol. % S-OPF to become an alternate reinforcement material to WGF.

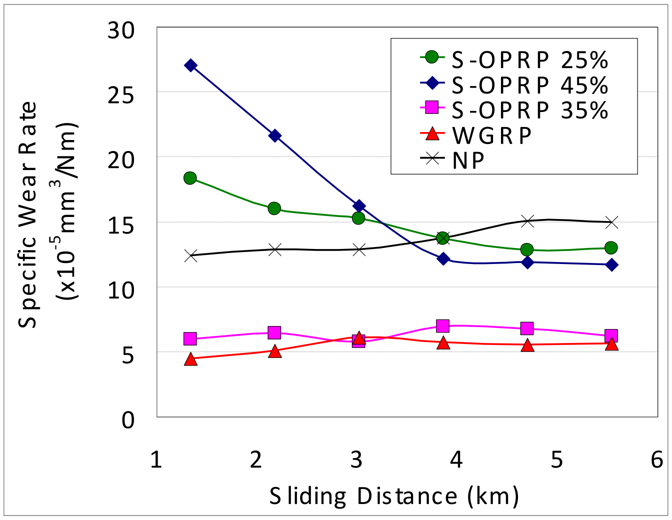


Fig. 2 Specific wear rate versus sliding distance

3.2 Effect of sliding distance on the friction

Fig. 3 shows the changes in the friction coefficient with respect to the sliding distance for NP, S-OPRP and WGRP composites. Basically, the figure shows that the friction coefficient increases when the sliding distance continues. WGRP composite exhibits lower friction coefficient compared to the other composites. The S-OPRP composites with 25 and 45 Vol.% shows a fluctuated friction coefficient. Meanwhile NP shows a stable result after 1.5km sliding distance. S-OPRP composite with 35 Vol.% introduces almost constant friction coefficient (about 0.9). WGFs had enhanced the properties of polyester by introducing a low friction but the constancy in friction coefficient of 35Vol. % S-OPFs is still considered a challenge to WGFs.

The high friction coefficient of the polyester composites based on natural fibres has been reported in previous work done on jute and coir fibres [12, 16]. The high interaction between the asperities in contact of both surfaces led to the higher friction coefficient, i.e. high resistance to the shear. It can be suggested that solid lubricant fillers would reduce the friction coefficient of such composites.

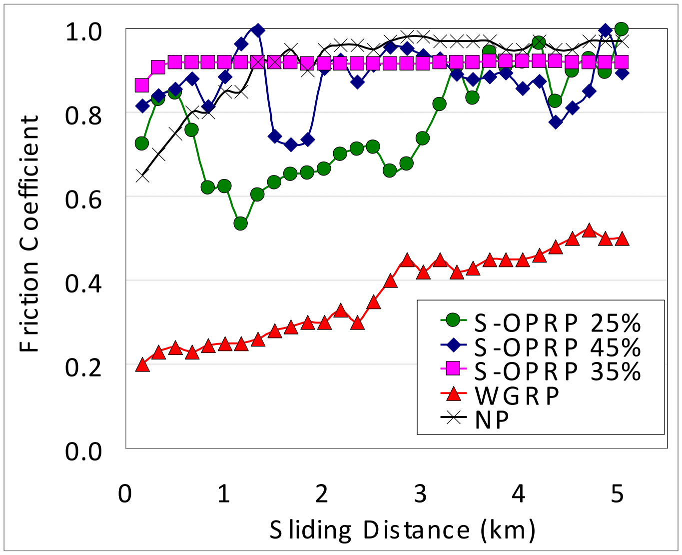


Fig. 3 Friction coefficient versus sliding distance

3.3 Effect of sliding distance on interface temperature

The effect of sliding distance on interface temperature was indicated by Fig. 4. All composites and NP had basically generated more and more heat when the sliding distance increased; especially for NP, the absent of any fibre in polyester had made its interface temperature increased at the fastest rate. For the composites, the rise in interface temperature is the result of increasing friction. The WGRP composite showed the rising temperature which is slightly faster then the S-OPRP composites. For S-OPRP composite with 35Vol. %, the interface temperature was increased at the approximate rate of 1.6 °C in 1km which is more or less equal to the S-OPRP composites with 25 and 45Vol. %. WGRP composite in contrast, has an approximate rate of 2.5 °C per 1km. S-OPFs (25, 35 or 45Vol. %) are once again prove that enhance the performance of polyester and more preferable based on the degree of heat generated.

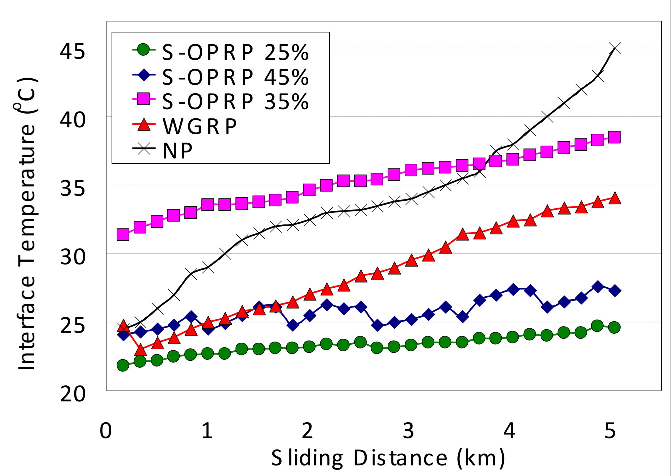


Fig. 4 Interface temperature versus sliding distance.

3.4 Worn surface studies

Fig. 5 shows the worn surface of 35Vol. % S-OPRP composite. In Fig. 5b, the polyester regions are highly deformed and plastic deformation can be seen. Polyester debris seems to be transferred to the fibrous regions covering the end of the fibres and filling the gap between the fibres and polyester during the sliding, i.e. low removal of material from the composite surface. This could be the reason of the lower specific wear rate of 35 Vol.% S-OPRP. Compared to Fig. 6, 45 Vol.% S-OPRP composites, some of the fibres from the bundle were pulled out and exposed to the sliding. Moreover, the higher volume of the fibre on the surface prevented the fibres to be adhered well on the resinous regions which became lose and easy to be removed. Thus, 45Vol. % S-OPRP showed high specific wear rate compared to the 35% one. The worn surface of S-OPRP composites with 25Vol. % is represented in fig. 7. Fig. 7 shows cracks in the resinous region neat the fibres. Moreover, some of the fine fibres, from the bundle, are exposed to the composite surface and become lose. Furthermore, in Fig. 7b, a sign of fibre debonding can be noticed. In other word, the wear mechanism at 25Vol.% is predominant by pull out and debonding of fibres, and micro-cracks in the resinous regions. Such mechanisms were not seen in the 35Vo.% composite which could be the reason of the higher wear performance of this composite.

The high deformation occurred on the surface of the 35Vol% and 45Vol%, Figs. 5 and 6, indicates that the wear mechanism is predominant by adhesion especially in the resinous region. In other words, high interaction between the aspirates in contact led to the high friction coefficient, Fig. 3.

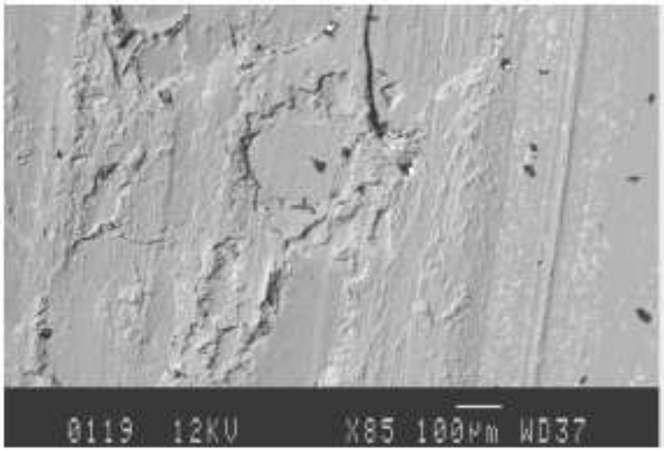


Fig. 5 SEM micrographs of the worn surface of S-OPRP (35%).

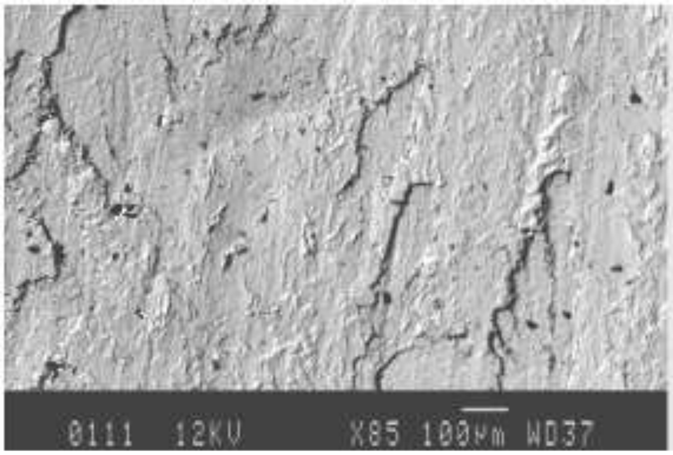


Fig. 6 SEM micrographs of the worn surface of of S-OPRP (45%).

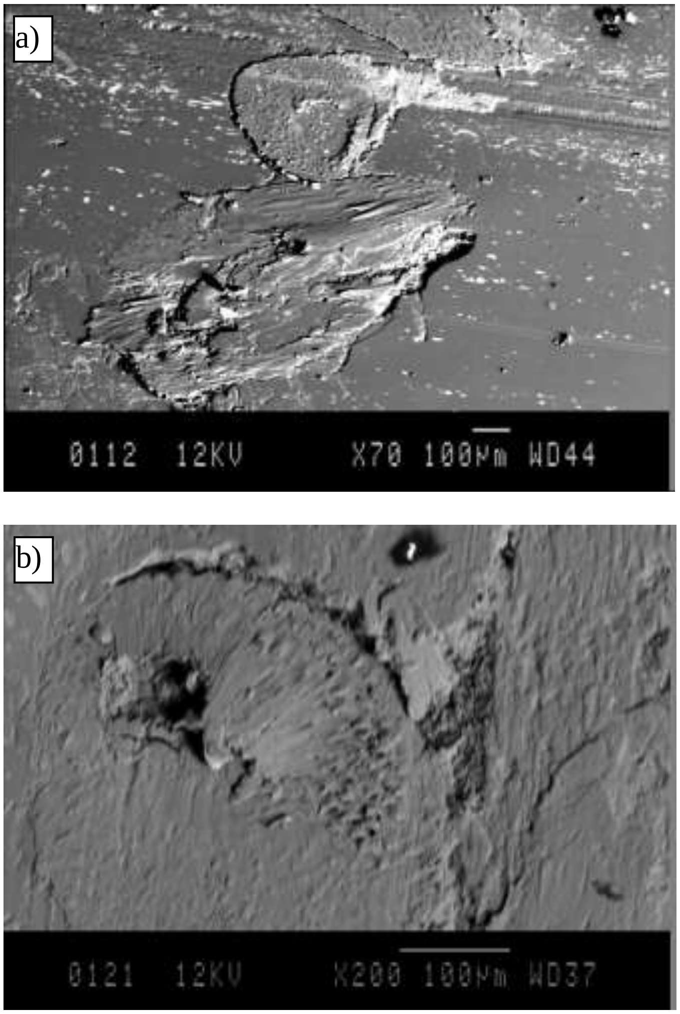
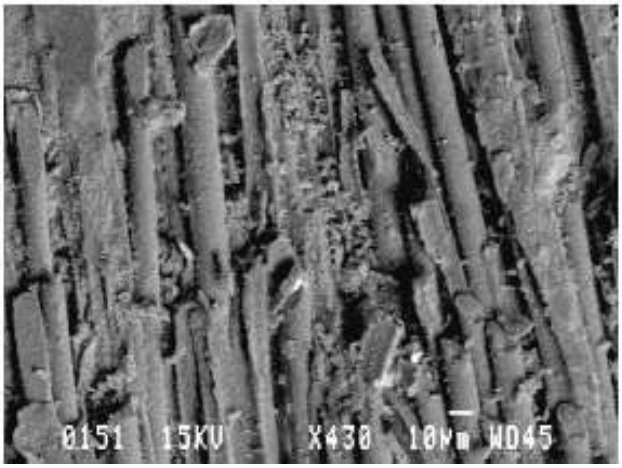


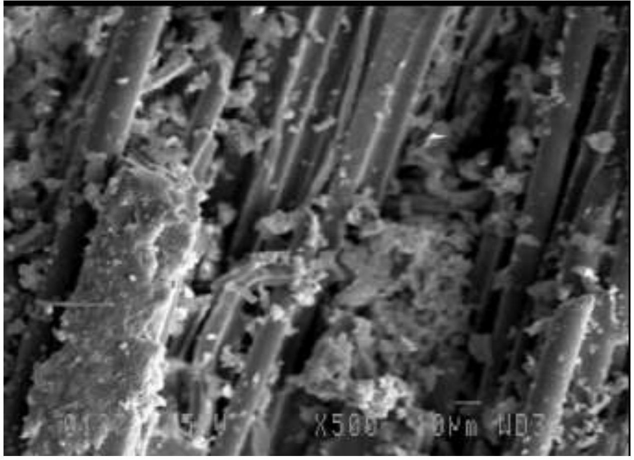
Fig. 7 SEM micrographs of the worn surface of S-OPRP (25%).

The worn surfaces of the WFRP composite are shown in Fig.8. It can be seen that debonding, breakage, pull out of fibres. Furthermore, fine polyester debris are randomly appeared between the lose fibres. In Fig. 8b, the polyester regions seem to be softened during the sliding. This weakened the surface of the composite which in turn led to fracture some of the polyester part. However, exposure of the hard phase of the composite (glass fibres) on the rubbing surface could be the reason of the low specific wear rate of the WFRP composite. This has been reported before [6]. It is well known that the hardness of glass fibre is much higher than the polyester and natural fibres.

On the worn surface of the polyester composite based on natural fibre, there is less pull out of fibres as seen on the WGRP. The poor interfacial adhesion of glass fibres with the polyester made the natural fibres as reinforcement highly competitive to the glass one.



a) *Showing debonding, pull out and breakage of fibres*



b) Showing softened and lose polyester debris

Fig. 8 SEM micrographs of the worn surface of WGRP.

4.CONCLUSION

1. WGRP and 35Vol. % S-OPRP composites have a similar specific wear rate which in the range of 3 to 8x10^{-5}mm^3/Nm.
2. S-OPRP composite with 35Vol. % shows high friction coefficient of 0.9. This was due to the high deformation on the surface increases the interaction between the aspirates in contact.
3. Volume fraction of the natural fibre had very strong influence on the wear and frictional behaviour of polyester composites.
4. 35Vol.% S-OPFs are capable to replace the WGFs for polyester composites.

REFERENCES

[1] Jochen Gassan, “A study of fibre and interface parameters affecting the fatigue behaviour of natural fibre composites”, Composites Part A 33, 1, 2002, pp. 369-374.

[2] William D.Callister, Jr. Materials Science And Engineering, An Introduction. New York John Wiley and Sons, Inc, 2003.

[3] Kenneth C Ludema. Friction, Wear, Lubrication, A Textbook in Tribology. Florida CRC Press, 1996.

[4] Hasim Pihtili and Nihat Tosun, "Investigation of the wear behavior of a glass-fibre-reinforced composite and plain polyester resin", Composites Science and Technology 62, 4, 2002, pp.367-370.

[5] A. Avci, H. Arikan and A. Akdemir, "Fracture behavior of glass fiber reinforced polymer composite", Cement and Concrete Research 34, 2, 2004, pp.429-434.

[6] Thomas Ø. Larsen, Tom L.Andersen, Bent Thorning, Andy Horsewell and Martin E. Vigild, "Comparison of friction and wear for an epoxy resin reinforced by a glass or a carbon-aramid hybrid weave", Wear 262, 4, 2007, pp.1013-1020.

[7] Martina Wollerdorfer and Herbert Bader, "Influence of Natural Fibres on the Mechanical Properties of biodegradable polymers", Industrial Crops and Products 8, 1, 1998, pp.105-112.

[8] Khosrow Ghavami, Romildo D. Toledo Filho and Normando P. Barbosa, "Behaviour of Composite Soil Reinforced with Natural Fibres", Cement and Concret Composites 21, 2, 1999, pp.39-48.

[9] M. Mizanur Rahman, Mubarak A. Khan, "Surface Treatment of Coir (Cocos Nucifera) Fibers and Its Influence on the Fibers' Physico-Mechanical Properties", Composites Science and Technology 67, 1, 2007, pp.2369-2376.

[10] Min Zhi Rong, Ming Qiu Zhang, Yuan Liu, Gui Cheng Yang and Han Min Zeng, "The Effect of Fiber Treatment on the Mechanical Properties of Unidirectional Sisal-Reinforced Epoxy Composites", Composites Science and Technology 61, 1, 2001, pp.1437-1447.

[11] Jochen Gassan and Andrzej K. Bledzki, "Possibilities for Improving the Mechanical Properties of Jute/Epoxy Composites by Alkali Treatment of Fibres", Composites Science and Technology 59, 1, 1999, pp.1303-1309.

[12] El-Sayed, A. A., El-Sherbiny, M. G., Abo-El-Ezz, A. S. and Aggag, G. A. (1995). Friction and wear properties of polymeric composite materials for bearing applications. Wear, 184(1), 45-53.

[13] Chand, N. and Dwivedi, U.K. (2006). Effect of coupling agent on abrasive wear behaviour of chopped jute fibre-reinforced polypropylene composites. Wear, 261(10),1057-1063.

[14] Hashmi, S.A.R., Dwivedi, U.K. and Chand, N. (2007). Graphite modified cotton fibre reinforced polyester composites under sliding wear conditions Wear, 262(11-12), 1426-1432.

[15] Hashmi, S.A.R., Dwivedi, U.K. and Chand, N. (2006) Friction and sliding wear of UHMWPE modified cotton fibre reinforced polyester composites. Tribology letter, 21(2), 79-87.

[16] B. F. Yousif, Frictional and Wear Performance of Polyester Composites Based on Coir Fibres, Proc. IMechE, Part J: J. Engineering Tribology, 2008, accepted for publication.