A REVIEW OF THE TRIBOLOGICAL PERFORMANCE ON POLYMERS FILLED WITH INORGANIC PARTICULATE FILLERS

V. Rodriguez[1], J. Sukumaran[1], Y. Perez[1], P. De Baets[1]

[1] Ghent University, Laboratory Soete, Belgium

Abstract

There are many technical applications in which friction and wear are critical issue. Polymers are often filled with particulate materials to enhance the tribological behaviour and a physical and mechanical property as well. The composites made with such fillers are amenable to common molding processes unlike fiber-reinforced composites which makes them economically. A lot of studies on the tribological behaviour of filled polymers have been made. The representative results from such studies are presented in this paper. New developments are still under the way to explore other fields of applications for these materials and to modify their properties for more extreme loading and environmental temperature conditions. Inorganic particles are well known to enhance the mechanical properties of polymers, which has been extensively investigated in the past. It has been found that particle size plays an important role to improve some mechanical properties such as toughness and stiffness. The mechanism of the improvement in wear behaviour is discussed by referring to the transfer film characteristics such as texture, uniformity and thickness as well as bonding to the counterface surface.

Keywords: friction, wear, fiber-reinforced.

1 INTRODUCTION

Tribology deals with the friction between two objects, how friction causes wear (loss of material on the contacting surfaces) and how lubrication can minimize wear. Polymers composite materials, is one of the most rapidly growing classes of tribological materials.

Polymer composite materials are employed in number of applications because they offer properties that cannot be obtained with pure polymers. Whereas continuous fiber-reinforced polymer are the most perform ant for enhancement of mechanical as well as tribological properties, they suffer from the disadvantage of processing because the traditional production processing techniques such as injection moulding and extrusion etc cannot be used with such composites. This makes these composites rather expensive. Instead of continuous fibers, chopped fibers are used as reinforcement for the above production processes, however the considerable improvement in mechanical properties is lost and the tribological properties also suffer considerably. As an alternative, filled polymer composites with inorganic compounds have been found very attractive because they can be processed easily and inexpensively and at same time offer very superior tribological properties comparable to those of the fiber-reinforced polymers.

These fillers are micro and nano meter sizes. Many kind of inorganic materials have been used as fillers in polymers such as metal powders, minerals, oxides, carbon and solid lubricants. Many inorganic compounds in micro and nano sizes have been found to be very effective in improving the tribological behaviour. Solid lubricant fillers such as graphite, PTFE have shown effectiveness in reducing the coefficient of friction and also increasing the wear resistance in many cases.

This paper presents some previous investigations in how various structures and compositions of polymers composites influence friction and wear behaviour. It is important to consider the differences containing different fillers and/or reinforcements for technical applications.

2 CONSEQUENCE OF FILLERS ON FRICTION AND WEAR

Fillers are added to the polymers in order to improve tribological properties such as wear resistance and friction coefficient. One of the most frequently configuration for the determination of the tribological behaviour of reinforced polymers is that of polymer-on metal sliding, where the polymeric material slides against a metallic counterface, such as pin-on-disk test, pin-on-plate test, flat on flat test, pin-on-ring, etc. This system has revealed that is useful for two reasons: under proper conditions, the polymer after the transfer films formation becomes self-lubricating on reducing adhesion effects, the wear and friction coefficient are low; and the metallic counterface has high thermal conductivity thus effectively avoiding a large build-up of heat at the wear interface that would degrade the performance of the polymer.

The lubricating additives fillers have an interior mechanism, such as polytetrafluoroethylene (PTFE) and graphite that are incorporated in the polymer matrix to reduce the friction coefficient and thus the shear stresses in the mating surfaces. Short aramid (AF), glass (GF), or carbon (CF) fibres are used to increase the creep resistance and the compressive strength of the polymer matrix system used. Normally the matrix should posses a high temperature resistance. There are significant differences in the tribological behaviour of the composites with specific fillers and polymers that have been investigated.

Previous studies by Bahadur and Gong [1] have been incorporate in polyetheretherketone (PEEK) matrix with copper-based inorganic compound fillers such as CuO, CuS and CuF_2 have shown benefits in nearly all of their uses in tribological applications and effectiveness of the copper compound. The friction and wear experiments were performed in pin-on-disk configuration with the polymer pin against hardened steel disk. It was found that CuO and CuS are very effective in reducing the wear rate of PEEK and PA, whereas ZnF_2, ZnS and PbS increased the wear rate of PA11 [2]. The wear resistance of polyphenylene sulphide (PPS) could be enhanced by the addition of CuS, Ag_2S or NiS, but reduced by CaF_2, ZnF_2, SnS, PbSe or PbTe. It was concluded that an initial stage of the transfer film develops due to the adhesion and interlocking of the polymer fragments into metal asperities during sliding.

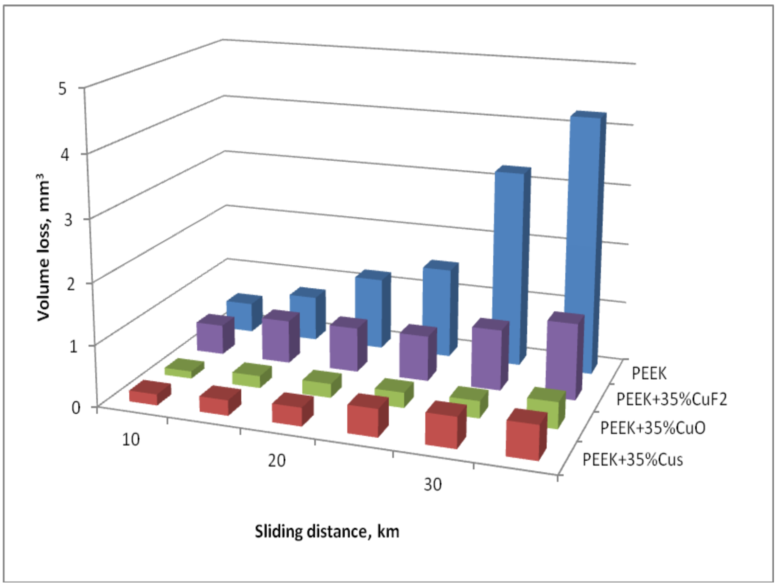

Figure 1. Results reported by Bahadur and Gong with the test conditions: sliding velocity 1.0 m/s, contact pressure 0.654 MPa, counterface roughness 0.11 μm Ra.

The figure 1. shows that all the fillers reduced wear and the ability of the fillers in reducing wear. The transfer film develops due to the adhesion and the interlocking of the polymer fragments into the metal during sliding. Those inorganic particles producing the mechanical adhesion between the transfer film and the metallic counterplate, which leads to improved, wear resistance.

2.1 Effect of the particle dimension

Other aspects of this subject is the dimension of the particle because when reduced down to nanoscale level (<100nm), the wear performance of these nanocomposites is significantly different compared to that of micron particle filled composites. The fine particles contribute better to the property improvement under sliding wear conditions than larger particle. In a recently review Xing et al [3] pointed out on spherical silica particles filled epoxy when particle size varied from 120 to 510 nm. The results showed that various kinds of SiC particles, i.e., nano, micron and whisker, could reduce the friction and wear when incorporated into a PEEK matrix at constant filler content, e.g., 10wt % (~ 4vol %). However, nanoparticles resulted in the most effective reduction and they help to the formation of a thin, uniform, and tenacious transfer film, which led to this improvement.

The inclusion of micrometer scale of inorganic particles helps to enhance the bonding between the transfer film and the metallic counterpart, which leads to improved wear resistance. For example, Schwartz and Bahadur [4] demonstrated that Ag_2 and CuS reduce wear of the polyphenylene sulphide (PPS), whereas ZnF_2 and SnS led to higher wear rates. They hypothesized that this behaviour was due to whether the filler particles deformed plastically under compression as Ag_2S and CuS did, or crumbled under load as ZnF_2 and SnS did. Zhao and Bahadur [5] showed that Ag_2S and NiS enhanced the wear resistance of PPS while PbSe and PbTe degraded its wear resistance. In order to show the difference in wear behaviour, the wear results for PPS filled NiS and PbSe fillers are showing in the figure 2 and 3.

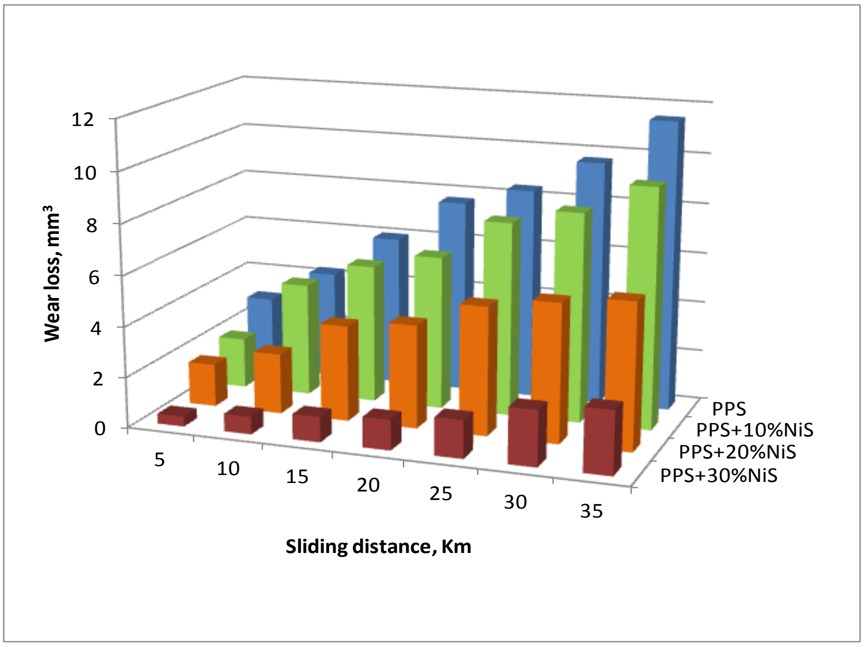

Figure 2. Results reported by Zhao and Bahadur of the wear loss of PPS filled with three difference proportions of NiS with a test conditions: sliding distance speed 1.00 m/s, nominal pressure 0.65 MPa, counterface roughness 0.10 μm Ra

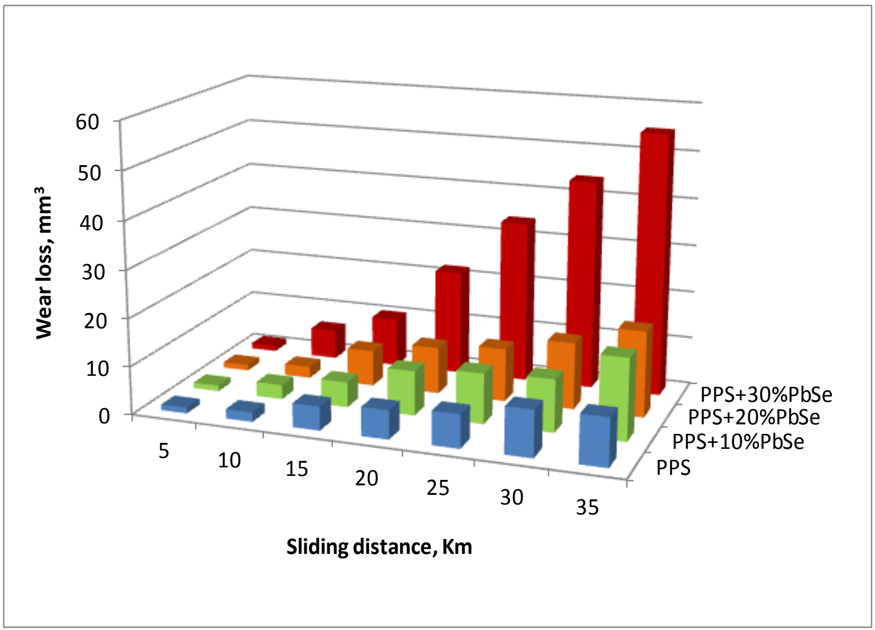

Figure 3. Results reported by Zhao and Bahadur of the wear loss of PPS filled with three difference proportions of PbSe with a test conditions: sliding distance speed 1.00 m/s, nominal pressure 0.65 MPa, counterface roughness 0.10 μm Ra.

In order to show the difference in wear behaviour, the wear results for PPS filled NiS and PbSe fillers are showing in the figure 2 and 3. The diagram for unfilled PPS and that filled with three proportions of NiS show that the effect of 10vol% NiS a 30vol% NiS the wear rate decreased by significant amount. The coefficient of friction of PPS decreased with the addition of filler and in the higher proportions of filler (30vol% NiS) the smaller was the coefficient of friction. Opposing the wear rate of PPS show that the higher proportions of PbSe the higher was the wear rate. However, the coefficient of friction of PbSe filled PPS decreased with the addition of filler and the higher the filler proportion, the lower was the coefficient of friction. Considering their abrasive nature, very small work has been done with the micro-sized hard particles of the steel counterpart, i.e. silicon carbide SiC, alumina, etc. They are directly correlated with the real average distance of the two sliding surfaces, which strongly affects the formation of a transfer film and they are able to reduce wear in the PPS matrix composites.

2.2 Effect of the nanoparticles fillers

In tribological behaviour it has been found that the size effect is an important role because the nanoparticles are effective in increasing wear resistance in much smaller volume percentages than the microparticles fillers. For example, micro-size fillers show utmost tribological behaviour benefit at volume fractions of 25 to 35 vol% while nanoparticles often produce optimal results from 1 to 3 vol%.

In some works the morphologies of the nanoparticles dispersion were not provided in detail, it should be clear that high filler contents lead to deterioration in the wear properties which may be due to a tendency of particle agglomeration. It is of high importance that the nanoparticles are uniformly dispersed rather than being agglomerated in order to yield a good property profile, in general. It was found by Cho and Bahadur [6] that the nano-sized of CuO in PPS increased the wear resistance, as did the micro-sized fillers of the same compound, with an optimal fraction of 2 vol% nanoparticles versus 35 vol% microparticles. In the other hand, Zhang et al.[7] on a series of epoxy-based composites. The latter contained different amounts of polytetrafluoroethylene (PTFE) powders and graphite flakes additionally reinforced with various quantities of short carbon fibers (SCF) and nano-TiO2 (300nm). The best wear resistant composition was found as a combination of nano-TiO2 with conventional reinforcements.

Nanoparticles filler behave similar to the microparticle fillers in respect to the modification of the tribological behaviour of the polymer. However, whereas the benefits in terms of the reduced wear are obtained with 30-35vol% microparticle filler proportion, the corresponding proportion for nano fillers is 1-3%vol. This is an immense advantage considering that most of these fillers are expensive. However, the filler is nano size is more expensive that the filler in micro size because of the increased processing cost.

3 MECHANISMS OF WEAR

As seen from the previous part of this paper the wear resistance of polymers is increased when they are filled with some fillers and decreased with some others. This has been the subject of investigation by many researches but further work is needed for optimum prediction. Some have looked at the mechanical aspects of the fillers while others have paid attention to the modification of the physical processes involved in sliding by fillers. It is important to follow some main notes behind the reduction in wear filled polymer composites like:

- Hard fillers, the bulk of the load is shared by the hard fillers so the soft polymer is subjected to lower load, this reduces the damage to the polymer sliding surface.

- The fillers help in the formation of transfer film on the metallic counterface which promotes sliding of the polymer surface against its own transfer film.

- The effective fillers increase bonding of transfer film to the counterface so that the loss of transfer film from the counterface is reduced during sliding which effectively reduces wear.

The wear produced by the used of filler particles has been theorized to be due to the ability of hard fillers to partially support normal loads during sliding. The use of a filler material that is stiffer than the polymer matrix may lead to a significant amount of the normal load being carried by the filler particles as opposed to the polymeric material. On the other hand, hard filler particles can build up at the wear interface and thus increase wear in some instances.

4 CONCLUSIONS

In the present study we showed that the use of polymers and polymers based composites for technical applications has grown rapidly over the past few years, in which low friction and low wear must be provided. It has been shown that some filler materials dramatically improve the wear resistance of polymers sliding against metals. The filler materials help in the formation of a smooth, uniform and thin transfer film on the metal countersurface. Several examples from the open literatures as well as from the research groups of the authors were used for this investigation.

The particle sizes are diminishing down to nanoscale, significant improvements of the wear resistance of polymers were achieved at very low nano-filler content (1-3vol %). This subject need further investigated the reasons why the much reduced size of the fillers yields such a significant improvement in the wear properties.

Since some filler improve the wear resistance while other does not, it would be of immense benefit if enhanced wear resistance. However, further work is needed for optimum prediction.

5 ACKNOWLEDGEMENTS

This investigation was supported and funded by FWO. Research (FWO grant number: 3G070108) was performed under a cooperative in Ghent University (UGent).

6 REFERENCES

[1] S. Bahadur and D. Gong, Anderegg JW. The role of cooper compounds as fillers in the transfer film formation and wear of nylon. Wear 1992; 207-223.

[2] K. Friedrich, Z. Zhang, Alois K. Schlarb. Effects of various fillers on the sliding wear of polymer composites. Composites science and technology 2005; 2329-2343.

[3] Xing XS, Li RKY. Wear behaviour of epoxy matrix composites filled with uniform sized sub-micron spherical silica particles. Wear 2004, 21-26.

[4] Schwartz CJ, Bahadur S. Studies on the tribological behaviour and transfer film-counterface bond strength for polyphenylene sulfide filled with nanoscale alumina particles. Wear 2000, 261-273.

[5] Zhao. Q, Bahahur S. A study of the modification of the friction and wear behaviour of polyphenylene sulfide composites in sliding against tool steel. Wear 1998, 245-251.

[6] M.H Cho and S. Bahadur. Effect of transfer film structure, composition and bonding on the tribological behaviour of polyphenylene sulfide filled with nanoparticles of TiO_2, ZnO, CuO, and SiC. Wear 2005, 1411-1421.

[7] Zhang MQ, Rong MZ, Yu SL, Wetzel B, Friedrich K. Effect of particle surface treatment on the tribological performance of epoxy based nanocomposites. Wear 2002, 1088-1095.