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Effects of various fillers on the sliding wear of polymer composites

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Abstract

Short fibre reinforced polymer composites are nowadays used in numerous tribological applications. In spite of this fact, new developments are still under way to explore other fields of application for these materials and to tailor their properties for more extreme loading conditions. The references given at the end of this review describe some of these developments. In the present overview further approaches in designing polymeric composites in order to operate under low friction and low wear against steel counterparts are described. A particular emphasis is focused on special filler (including nanoparticle) reinforced thermoplastics and thermosets. Especially, the influence of particle size and filler contents on the wear performance is summarised. In some of the cases, an integration of traditional fillers with inorganic nanoparticles is introduced and presents an optimal effect. Furthermore, some new steps towards the development of functionally graded tribo-materials are illustrated.

Keywords: Wear; Polymer composites; Nanocomposites

1. Introduction

There are more and more technical applications in which friction and wear are critical issues. Polymer composites containing different fillers and/or reinforcements are frequently used for these purposes. In particular, they are now being used as sliding elements, which were formerly composed of metallic materials only. Nevertheless, new developments are still under way to explore other fields of application for these materials and to tailor their properties for more extreme loading and environmental temperature conditions. One example for automotive applications is the new generation of control arm mountings or ball joints in the car chassis technology, in which higher loads and temperature are acting on a tribo-couple. In this case, polymer composites will be operated at relatively high environmental temperature, e.g., 120 °C, and the demand for high wear resistance becomes increasingly important. To understand these properties at severe operating conditions is directly related to the safety and service life of the technical components considered.

Inorganic particles are well known to enhance the mechanical properties of polymers, which has been widely investigated in the past decades. It has been found that the size of the particles plays an important role to improve, in particular, stiffness and toughness simultaneously. Reducing the particle size to a nanoscale level is assumed to reach a significant efficiency. Nanoparticle filled polymers, so-called polymer nanocomposites, are very promising materials for various applications. They are expected to replace polymers, polymer blends and their traditional composites in products produced by melt processing techniques. This prediction is justified by the improvements in properties without sacrificing the melt rheological properties. The

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major feature of polymer nanocomposites is their huge interfacial surface area, which may result in a peculiar physical network structure of three-dimensional interphase (well reviewed recently in [1]). Nano-fillers are also expected to be able to strongly influence the wear performance of polymers and composites.

By the way, how these materials must exactly be designed depends on the requirement profile of the particular application. That means the tribological characteristics, i.e., the friction coefficient and the wear resistance, are no real material properties, but depend on the system in which these materials have to function. Sometimes, a high coefficient of friction, coupled with low wear, is required (e.g., for brake pads or clutches). In most of the cases, however, it is of primary concern to develop polymeric composites that possess low friction and low wear properties under dry sliding conditions against smooth metallic counterparts (e.g., as gears or bearings).

For the determination of the tribological behaviour of polymer materials in the laboratory, standard tests are used. The pin-on-disk test, one of the most frequently used test configurations, is described elaborately. It allows determining the most important tribological property, the specific wear rate W_s of the material to be optimised, by using the equation,

$$W_s = \frac{\Delta V}{F_N \cdot L} [\mathrm{mm}^3/(\mathrm{N\,m})] \quad (1)$$

in which ΔV is loss in volume, F_N is normal load, and L is sliding distance. The inverse of the wear rate is usually referred to as the wear resistance of a material.

The choice of the type of wear test configuration must be based on the tribo-technical system under consideration. This determines the elements of the basic structure of the tribo-system which yields information on the existing wear mechanisms (surface variations), and the loss of material (wear rates). Therefore, tribological testing of the materials under laboratory test configurations can only be considered as a helpful screening tool. The final choice of the right material combination is always dependent on the results of subsequent field tests by the use of the real structural components. All cases discussed in the following are mainly related to sliding wear of polymer or composite specimens against polished metallic counterparts.

2. Internal lubricants and short fibres

In order to improve the friction and wear behaviour of polymeric materials, one typical concept is to reduce their adhesion to the counterpart material and to enhance their hardness, stiffness and compressive strength. This can be achieved quite successfully by using special fillers. To reduce the adhesion, internal lubricants such as polytetrafluoroethylene (PTFE) and graphite flakes are frequently incorporated. One of the mechanisms of the corresponding reduction in the coefficient of friction is the formation of a PTFE-transfer film on the surface of the counterpart [2]. 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 [2–6]. Normally the matrix should possess a high temperature resistance and have a high cohesive strength. However, sometimes it is also advantageous to have a PTFE based matrix in which a stiffer and more wear resistant polymer phase along with other fillers provide more optimum conditions for the tribological situation under particular consideration, e.g., its use at cryogenic temperatures [7]. Additional fillers that enhance the thermal conductivity are often of great advantage, especially if effects of temperature enhancement in the contact area must be avoided in order to prevent an increase in the specific wear rate. It should also be noted, that not all the fillers are of benefit to the wear performance of composites. The wear resistance is increased when fillers decompose and generate reaction products which enhance the bonding between the transfer film and the counterface [4], whereas other fillers decrease the wear resistance because they generate more discontinuities in the material. It is thus important to understand the growth, bonding and loss of transfer films, which are strongly related to the wear mechanisms. It should also be noted that chemical and mechanical interactions of transfer films are very complicated, therefore, further efforts to understand these relationships in more detail are still a subject of current and future studies [8,9].

Table 1 summarizes the specific wear rate of various filler modified and/or short fibre reinforced thermoplastic composite systems tested against steel counterparts on a block-on-ring test configuration. They have been developed for special applications in which low friction, high wear resistance and good thermal conductivity under sliding wear conditions against smooth steel counterparts were of great importance. It can be found that PTFE + 10 vol%Bronze + 10 vol%CF exhibits an excellent wear resistance. In particular, the addition of bronze improves significantly the tribological properties of the composite because of its outstanding thermal conductivity. This is, in fact, a good example to prove the effectiveness of this kind of filler for the design of a wear resistant polymer composite. The microstructure of such a material is shown in Fig. 1 [10] (in this case PTFE + 31.6 vol% PPS + 13.5 vol% CF + 3.9 vol% graphite, used in low temperature compressor applications). It should be mentioned that there are certainly many more compositions available on the commercial market, which, due to a lack of space, cannot all be listed here.