INFLUENCE OF SOLID LUBRICANT FILLERS ON THE TRIBOLOGICAL BEHAVIOUR OF PEEK COMPOSITES IN VACUUM

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ABSTRACT

PTFE containing composites are proven materials for tribological applications in vacuum environment. With the addition of solid lubricants their friction and wear behaviour can be further improved. In particular MoS_2 has a friction coefficient as low as 0.03 in vacuum. Thus the tribological behaviour of MoS_2 filled PEEK/PTFE composites was investigated in comparison to graphite filled materials. Results of high-vacuum friction tests of carbon fibre reinforced PEEK composites filled with PTFE, and MoS_2 or graphite as further solid lubricant are presented. Polymer samples were tested in pin-on-disc configuration continuously sliding against CrNi-steel. Depending on sliding speed and temperature, the MoS_2 filled composites showed high wear resistance and friction coefficients as low as PVD coatings.

1. INTRODUCTION

Ultra-high vacuum, a wide temperature range, presence of atomic oxygen, and limited applicability of liquid lubricants, make open space an extremely hostile environment for tribologically stressed components in satellites. In most of these systems, but also in vacuum technology on earth, in cryogenic or cleanroom environment, dry sliding, self-lubricating materials must be employed.

A promising polymeric material for such applications is polyetheretherketon (PEEK). It has a very low vapour pressure, which makes it suitable for vacuum applications. PEEK and PEEK composites are widely used for their good tribological characteristics in a large temperature range [1]. For applications in air, optimal performance is obtained by the addition of fillers and fibres such as carbon fibres, PTFE, and graphite.

Polytetrafluoroethylene (PTFE) is a proven material for the use in tribological applications in the broad temperature range from – 260 °C to + 260 °C in air, but also in vacuum [2, 3]. However, it has a strong tendency to cold flow which limits its applicability as a bulk material. However, some percent of PTFE in a high performance matrix, such as PEEK, improves the tribological properties distinctively

Graphite has excellent lubrication properties in normal atmosphere. However, a certain amount of water vapour is necessary for graphite lubrication, since the adsorption of water reduces the bonding energy between the hexagonal planes. Thus, it doesn't provide lubrication in vacuum environment, but its addition might improve the heat-dissipating characteristics of the polymer composite in some cases [4]. MoS_2 has a hexagonal crystal structure like graphite. However, it shows the intrinsic property of easy shear, which makes it effective in vacuum and the most widely used solid lubricant in vacuum environment [5].

In recent years, several studies on the tribological behaviour of composites and coatings in vacuum environment were conducted [6-10]. This paper presents the tribological behaviour of PEEK/PTFE composites filled with either MoS_2 or, for comparison, graphite, against steel in high vacuum under continuous sliding conditions.

2. EXPERIMENTAL

2.1. Tests Parameters

Tests wear performed in the high vacuum tribometer described in [6]. It was operated in configuration for continuous motion and the range of the temperature control was extended to -80.

The samples were arranged in flat-on-flat geometry and tested in high vacuum at different temperatures, loads and sliding velocities as indicated in Tab. 1.

During the measurements the normal and friction forces are recorded continuously. The wear was measured as weight loss by means of a high precision balance.

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Table 1. Test parameters

Sliding mode	continuous
Sliding velocity	0.01 m/s - 1 m/s
Contact pressure	1 MPa and 7 MPa
Test duration	20 hours
environment	Vacuum, 10^{-4} – 10^{-6} mbar
Temperature	-80°C – +20°C
Counter body	X5CrNi1810-Stahl (1.4301)

2.2. Materials

The composition of the PEEK materials is presented in Tab. 2. Materials were compounded by Ensinger Ltd and injection moulded as standard shouldered test bars at the Institute for Composite Materials (IVW, Kaiserslautern). Polymer composites were cut into pins with 4 x 4 mm^2 cross sections. As shown in Tab. 2, the materials are composed with a PEEK matrix filled with PTFE, carbon fibres and graphite (material 1G) or MoS_2 (material 4M).

Table 2*. Composition of the material (vol %)*

Material	PEEK	CF	PTFE	Graphite	MoS_2
1G	70	10	10	10	
4M	70	10	10		10

3. Results

Fig. 2 shows the friction coefficient, Fig. 3 the wear rate of the composites in vacuum between -80°C and 20°C at 1 MPa and 7 MPa contact pressure. Above room temperature, the friction coefficient of these PEEK composites doesn’t depend on the solid lubricant [7]. At lower temperature, however, the composite with MoS_2 has a significantly lower friction coefficient than the composite with graphite, reaching 0.013 at -80°C.

Wear rates of the polymer composites are presented in Fig. 3. Results indicate constant low values over the temperature range for MoS_2 composite. The graphite containing material has a higher wear rate which decreases, however, at room temperature.

By increasing the contact pressure to 7 MPa, the coefficients of friction slightly decrease but the difference is not as distinct as in the previous study with oscillating motion [6, 7]. The wear rate of MoS_2 composite, however, decreases significantly at higher contact pressure.

The development of friction with time at room temperature is shown in Fig. 4, at -80 °C in Fig. 5. The figures show the records for two polymer samples sliding on the same track. At room temperature a distinct running in behaviour occurs for about 10 h until friction stabilises at a coefficient of friction of 0.05. During the complete test time the scatter of the friction data was about 20 % with somewhat higher values after the running in maximum. Despite this scatter, a friction coefficient of 0.05 is very low for dry running tribosystems.

At a temperature of -80 °C the friction behaviour is further improved (Fig. 5). After a short running in phase of about 2 hours, friction stabilises for both samples. While sample 2 has a steady state value of about 0.01, which is in the order of extremely good prepared a-C:H-coatings, sample 1 reaches even lower values. Also the scatter is much lower than at room temperature. To exclude measurement errors, the force sensors were calibrated with a dead weight before and after the tests, and experiments were repeated twice. Thus, these very low friction data must be taken for real. Nevertheless, further investigations are necessary for confirmation and explanation of this very low coefficient of friction.

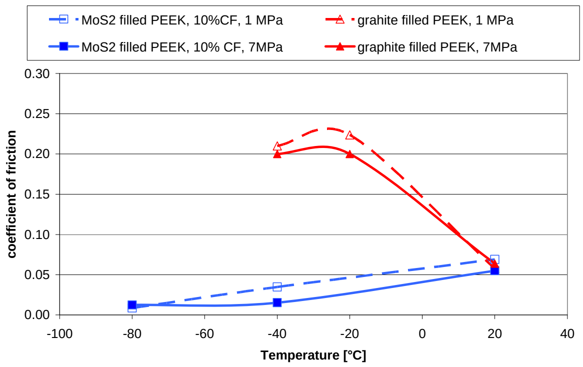


Figure 2. Coefficient of friction of MoS_2 filled PEEK in vacuum environment (v = 0.1 m/s)

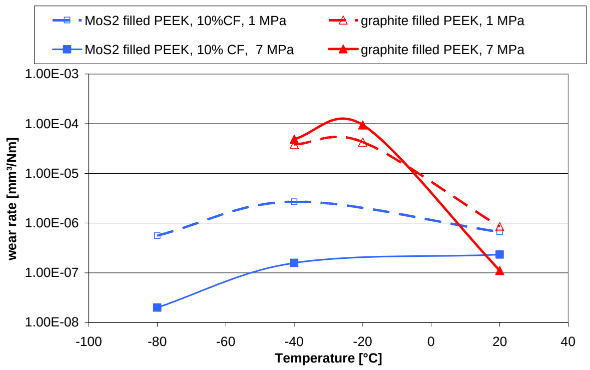


Figure 3. Wear rate of MoS_2 filled PEEK in vacuum environment (v = 0.1 m/s)

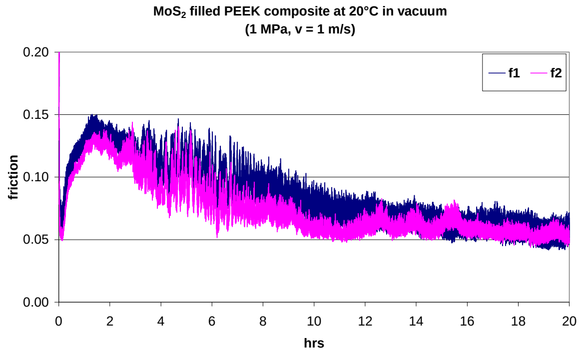


Figure 4. Friction vs. time of MoS_2 filled PEEK composite in vacuum at 20°C

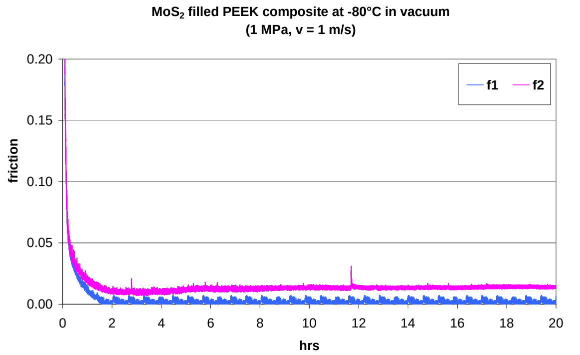


Figure 5 Friction vs. time of MoS_2 filled PEEK composite in vacuum at -80°C

4. SURFACE ANALYSES AND DISCUSSIONS

Fig. 6 presents the surface analyses of the polymer transfer onto the disc after the tests at 0.1 m/s and 1 MPa for the MoS_2 filled and graphite filled PEEK composite respectively at 20°C and -80°C or -40°C.

At 20°C, the influence of the solid lubricant is not significant since the friction behaviour is similar to MoS_2 or graphite filled composites. Fig. 6 indicates that in both cases, the solid lubricant is not uniformly transferred onto the counterface.

Decreasing the temperature, the friction behaviour between the two composites becomes different. As mentioned in [6], the deformation of the polymer composite decreases at low temperature due to its higher hardness. This could produce higher contact pressure locally. Since the performance of MoS_2 improves at high contact pressure, this would explain the lower friction coefficient at -80°C.

Fig. 6 shows that the lower friction coefficient (and wear rate) of the MoS_2 filled composite at -80°C is associated with a thin and homogeneous transfer film on the counterface. This corresponds also to a higher concentration of the MoS_2 at the surface of the composite as indicated in the EDX images (Fig. 6). This allows an effective lubrication between both interacting surfaces. On the other hand, the graphite filled composite produces a thick inhomogeneous transfer on to the disc (Fig. 6).

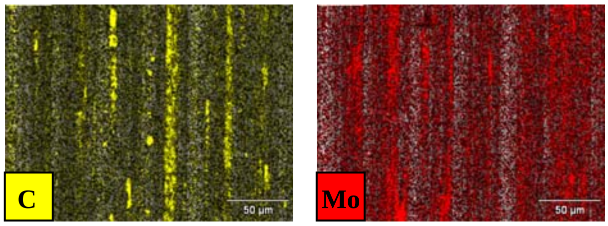


Figure 6. EDX maps of the disc surface of the after test against MoS_2 filled PEEK at 20 °C

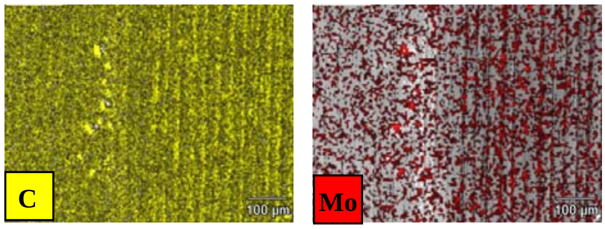
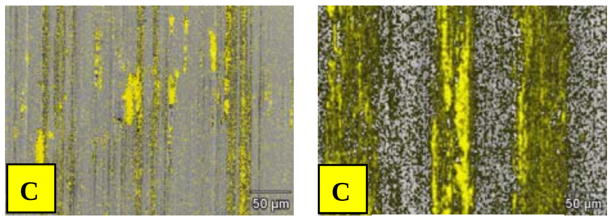
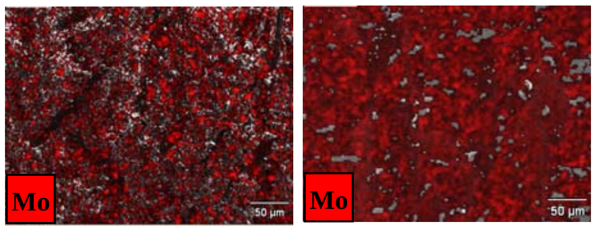


Figure 7. EDX maps of the disc surface of the after test against MoS_2 filled PEEK at -80 °C



T = 20 °C T = -40 °C

Figure 8. EDX maps of the disc surface of the after test against graphite filled PEEK



T = 20 °C T = -80 °C

Figure 7. EDX analyses of MoS_2 filled PEEK composite pin at 1 MPa

5. CONCLUSIONS

Friction and wear behaviour of PEEK composites filled with carbon fibres, PTFE, and graphite or MoS_2 were investigated in vacuum in the temperature range between - 80°C and +20°C. Results indicate that MoS_2 filled PEEK shows better tribological performance compared to the composite with graphite. Particularly, in the lower temperature range and at higher loads the friction behaviour is improved by the MoS_2 content. Surface analyses show that the lower friction coefficient and wear rate of the MoS_2 filled composite at -80°C is associated with a thin polymer transfer film on the counterface, with a higher concentration of MoS_2 at the surface of the composite.

6. ACKNOWLEDGEMENTS

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