Influence of the Temperature on the Tribological Behaviour of PEEK Composites in Vacuum Environment

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Abstract. This paper describes tribological experiments carried out with polyetheretherketone (PEEK), filled with carbon fibres and solid lubricants (polytetrafluoroethylene (PTFE), graphite or MoS₂), against steel discs. Oscillating sliding tests were performed in high vacuum environment in the temperature range between -40°C and +160°C. Results indicate that MoS₂ filled PEEK show the best tribological performance in vacuum. Particularly, in the lower temperature range and at higher loads the friction behaviour is improved by the MoS₂ content.

1. Introduction
For tribological components working under extreme conditions, such as vacuum environment, or broad temperature ranges, it is often a problem to achieve acceptable endurance of their friction parts. New material requirements are involved for these tribo-systems, in particular regarding operability and reliability.

For applications in high-vacuum and space-environments, in food-processing machines, or in semiconductor manufacturing equipment, self-lubricating materials must be employed. PEEK composites are widely employed for their good tribological characteristics in a large temperature range [1]. For applications in air, optimal performances were obtained with the addition of fillers and fibres such as carbon fibres, PTFE, and graphite.

It is well known that graphite has excellent lubrication properties in normal atmosphere. Water vapor is necessary for graphite lubrication, since the adsorption of water reduces the bonding energy between the hexagonal planes. Thus, it is not effective in vacuum environment, but its addition might improve the heat-dissipating characteristics of the polymer composite in some cases [2]. Like graphite, MoS₂ has a hexagonal crystal structure but with the intrinsic property of easy shear, which makes it effective in vacuum and the most widely used solid lubricant in vacuum environment [3].

At the Federal Institute for Materials Research and Testing, Berlin, several projects were conducted in the recent years, dealing with the tribological behaviour of friction couples in vacuum environment. This paper presents the tribological behaviour of PEEK composites filled with either MoS₂ or, for comparison, graphite, against steel in high vacuum in our standard and mostly asked temperature range between -40°C and +160°C.
2. Experiments

2.1. Materials
The composition of the PEEK materials is presented in table 1. Materials were compounded by Ensinger Ltd and injection moulded as standard shouldered test bars at the Institute for Composite Materials (IVW, Kaiserslautern). 304 steel discs were used as counterface.

| Material | PEEK | CF  | PTFE | Graphite | MoS$_2$ |
|----------|------|-----|------|----------|---------|
| A        | 70   | 10  | 10   | 10       |         |
| B        | 70   | 10  | 10   |          |         |
| C        | 78   | 12  |      | 10       |         |

2.2. Tests parameters
Tests were performed with a pin-on-disc configuration in oscillating sliding in the high vacuum tribometer VT1 at BAM [4]. Experiments at 1 MPa were carried out during 20 hours at room temperature, -40°C, 100°C and +160°C (TC1). Temperature cycles (TC2), which began with 20 hours at RT, followed by 30 min at -40°C, at 100°C and at 160°C, were also performed at 1 MPa and 7 MPa. The friction coefficients obtained with this “temperature cycle” were similar to the ones obtained after each 20 hour tests, except for material A at 160°C. Tests parameters are given in table 2.

| Test conditions | Environment | Contact pressure | Velocity | Temperature / Time     |
|-----------------|-------------|-----------------|----------|------------------------|
| TC1             | Vacuum 10$^{-5}$ mbar | 1 MPa          | 0.1 m/s  | 20 hrs at -40°C, 20°C, 100°C and 160°C |
| TC2             | Vacuum 10$^{-5}$ mbar | 1 MPa, 7 MPa   | 0.1 m/s  | 20 hrs at 20°C, then 30 min at -40°C, 100°C and 160°C |

3. Results
The following graphs (1-2) show the friction coefficient and the wear rate of the composites in vacuum between -40°C and 160°C at 1 MPa contact pressure after 20 hours. Under these conditions, the friction coefficient of PEEK composites doesn’t depend on the solid lubricant between RT and 160°C. At -40°C, however, the composite with MoS$_2$ has a significantly lower friction coefficient than the composite with graphite. The friction coefficient of the composite C, without neither MoS$_2$ nor graphite confirms the beneficial effect of MoS$_2$ at -40°C.

**Figure 1.** Friction coefficient of PEEK composites (TC1)

**Figure 2.** Wear rate of PEEK composites (TC1)
Wear rates of the polymer composites are presented in Figure 2. 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 high temperature.

By increasing the contact pressure to 7 MPa, the friction coefficient (Figure 3) increases for the graphite containing composite. On the other hand, the MoS$_2$ filled composite has an even lower friction coefficient that reaches 0.023 at -40°C.

4. Discussions
The influence of the solid lubricant is not significant between RT and 100°C at low contact pressure since the friction behaviour is similar to that without MoS$_2$ or Graphite. Under these conditions, the solid lubricant can not be efficiently transferred uniformly onto the counterface.

At -40°C however, the friction behaviour between the two composites is different. At low temperature, the deformation of the polymer composite decreases 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 -40°C.

Surface analyses show that the lower friction coefficient and wear rate of the MoS$_2$ filled composite at -40°C is associated with a thin transfer film on the counterface (Figure 5), which allows an effective lubrication between both interacting surfaces.

The experiments performed at higher contact pressure confirm the phenomena. While friction increases for the graphite filled composite at 7 MPa, it decreases with MoS$_2$ solid lubricant. This corresponds to a higher concentration of the MoS$_2$ at the surface of the composite at higher load as indicated in the EDX images (Figures 6 and 7). More details about the transfer film composition will be presented elsewhere.

Figure 3. Friction coefficient of composite A (TC2)

Figure 4. Friction coefficient of composite B (TC2)

Figure 5. SEM images of the steel counterface after tests in vacuum at 1 MPa and -40°C against a) composite A and b) composite B
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 -40°C and +160°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 -40°C is associated with a thin polymer transfer film on the counterface. While friction increases for the graphite filled composite at higher load, it decreases with MoS$_2$ solid lubricant, which corresponds to a higher concentration of MoS$_2$ at the surface of the composite.

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7. References
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