Investigation of fretting behaviour of TiN coatings at high temperature

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Fretting is a wear process induced by the reciprocating movement at small displacement amplitudes of a counter-body, and takes place in many technical systems. The contact region remains to a large extent isolated from the surrounding atmosphere. The debris formed and the surface reactions induced during fretting, play a major role in the fretting wear process.

Nowadays it is generally accepted that tribological contacts need to be analyzed based on a tribo-system approach. The energy dissipated by friction is the main input of energy in a tribo-system. Therefore all the energy-consuming processes in sliding contacts, inclusive wear, are directly or indirectly dependent on the dissipated energy.

The dissipated frictional energy is thus a key parameter determining the fretting behavior of coatings like PVD TiN. In this research work, the fretting behavior of TiN high-speed steel coatings sliding against corundum at temperatures up to 500 °C is presented and discussed.

High-speed steel ASP23 flat specimens quenched and tempered at a hardness of 63 HRC were polished to a roughness R_a 0.02 ?m and subsequently PVD coated with TiN. The 4 µm thick coatings were deposited using a Balzers triode ion-plating equipment (WTCM, Diepenbeek, Belgium). The roughness of the coating was 0.06 ?m (R_a). Polished corundum balls with a diameter of 10 mm, a hardness of 2000 HVN, and a surface roughness R_a 0.2 ?m, were used as counter-body. Fretting tests mode I were carried out in a high temperature fretting test rig described in detail in [1]. In this work, the temperature was varied between 60 °C and 500 °C, controlled by a thermocouple mounted on the TiN-coated specimen. This temperature is referred hereafter as 'test temperature', and is not the real contact temperature at the sliding fretting contact area.

After the fretting tests, the morphology of wear tracks was observed by scanning electron microscopy (SEM). Wear scars were investigated by laser profilometry (Rodenstock RM600), and the wear volume was obtained by integrating cross sectional profile areas as described earlier [2].

The tangential force was measured on-line during the fretting tests. The energy dissipated during the successive fretting loops was calculated based on the instantaneous values of the tangential force and displacement according to a procedure published earlier [3]. This cumulative dissipated energy was calculated for the different fretting tests performed.

Hysteresis loops corresponding to cycle 1,000 are shown in Fig. 1 for fretting tests performed at test temperatures between 60 °C and 500 °C. The coefficient of friction was derived from these hysteresis loops as the ratio between the mean value of the tangential force and the normal load applied. The evolution of the mean coefficient of friction during the fretting tests is shown in Fig. 2 for tests performed at temperatures between 60 °C and 500 °C. The use of a logarithmic scale for the number of cycles allows a better observation of the variation of the coefficient of friction during the running-in phase. The evolution of the coefficient of friction with the number of cycles agrees well with previous work [4], and is characterized by five periods. The first one is a running-in period with a low and constant coefficient of friction, followed by a second period where a rise of the coefficient of friction takes place. During the third period, the coefficient of friction reaches high values and remains more or less constant. Finally, a rapid drop of the coefficient of friction takes place and a steady state period is established till wear-through occurs.

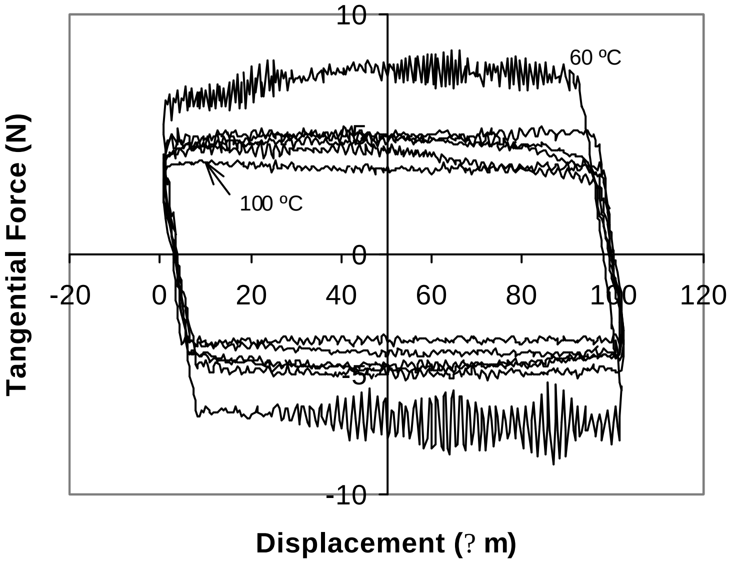

Figure 1 - Hysteresis loops corresponding to cycle 1,000 for fretting tests performed at test temperatures varying between 60 °C and 500 °C (normal load 10 N, displacement amplitude 100 µm).

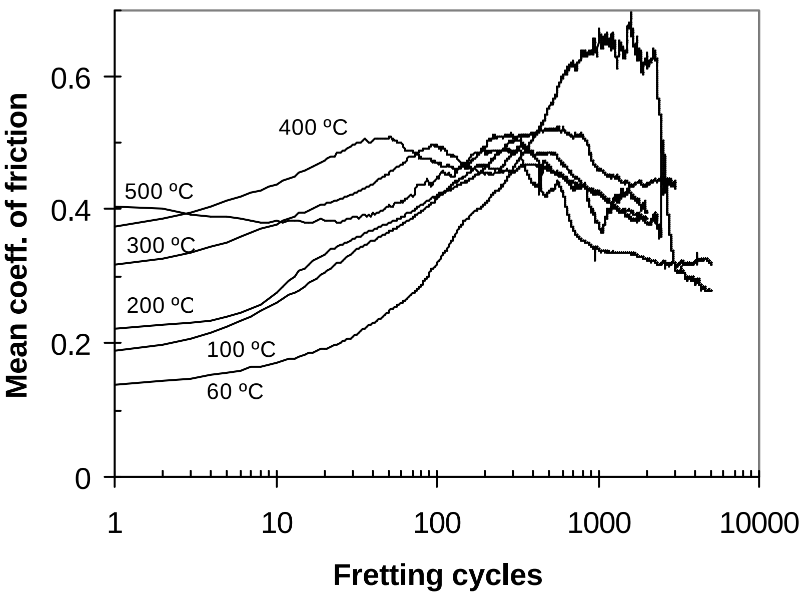

Figure 2 – Evolution of the mean coefficient of friction during the tests performed at temperatures in the range of 60 °C to 500 °C (normal load 10 N, displacement amplitude 100 µm).

Besides this general evolution appearing in all tests performed, some major differences between the tests were noticed. So, e.g., the coefficient of friction increases in the running-in period with increasing test temperature. The maximum value of the coefficient of friction in the third period is 0.7 for fretting tests done at 60 °C, while a value near 0.5 is noticed at all the other test temperatures. Finally, the number of fretting cycles at which the fourth period starts, decreases with increasing test temperature. Only the fretting test done at 500 °C is an exception to this trend.

The wear loss on TiN coatings tested at different test temperatures is plotted in Fig. 3 against the cumulative dissipated energy. In Fig. 3, data published by Mohrbacher *et al*. [3] on a similar material combination but tested at 23 °C, are represented as a dotted line. Mohrbacher found a linear relationship between the volumetric wear loss and the cumulative dissipated energy for fretting tests performed under gross slip conditions in ambient air of 23 °C, and at different relative humidity, normal loads, and frequencies. The test done presently at 60 °C fits well with the data of Mohrbacher, notwithstanding the fact that a completely different fretting test equipment was used with a different rigidity and frame structure. Even more interesting is to note that for the experimental data obtained at test temperatures between 100 and 500 °C in ambient air, a linear dependence is also noticed between dissipated energy and volumetric wear loss. The best linear fit for these high temperature fretting tests, has a slope comparable to the one reported by Mohrbacher, but the line is shifted so that a slightly higher wear loss is taking place at a given amount of dissipated energy.

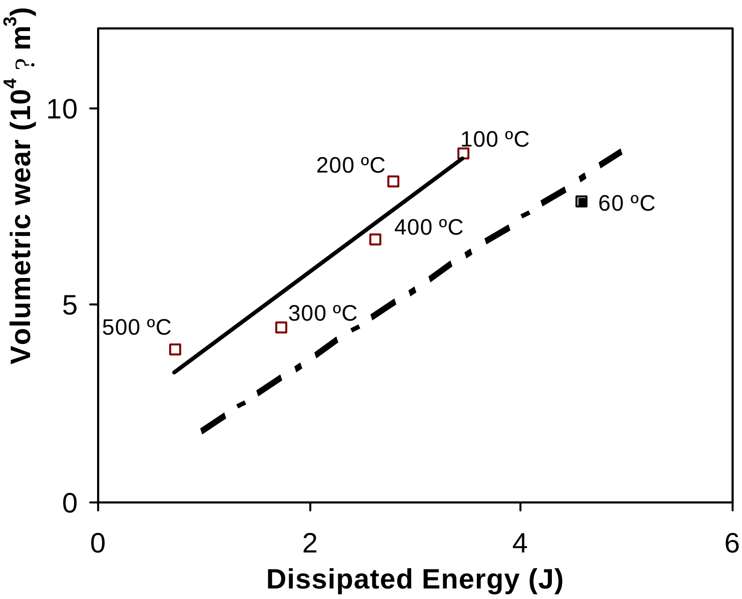

Figure 3 – Wear volume of TiN coatings as a function of the cumulative dissipated energy. Dashed line represents the results obtained at 23 ºC by Mohrbacher *et al* [3].

The shift in the fretting wear data obtained in at temperatures of 100 °C up to 400 °C in comparison to the fretting data obtained at 23 °C by Mohrbacher *et al.* (see Fig. 3), indicates that the wear degradation process is influenced by the test temperature in that range.

The results of the fretting test shown in Figures 2 can be explained as follows:

- during fretting tests done at 60 °C, the crystallization of the debris is induced by the frictional energy dissipated in the sliding contacts. Initiation of crystallization requires a large number of fretting cycles, and the coefficient of friction remains high during a large number of fretting cycles,
- during fretting tests performed between 100 °C and 400 °C, the dissipated frictional energy required to induce crystallization decreases since thermal oxidation becomes more active, and the coefficient of friction lowers after a smaller number of fretting cycles,
- for fretting tests performed at 500 °C and higher, the frictional behavior is different right from the start of the fretting tests. This is linked to a spontaneous thermal oxidation of TiN on exposure to ambient air at these temperatures as reported previously [7,10], so that the crystallization of the debris does not require any additional frictional energy.

From these experimental facts, it may be concluded that the test temperature during fretting tests acts as an additional input of energy contributing to the crystallization of the debris. At increasing test temperature, the frictional energy required to induce crystallization lowers. This conclusion agrees well with the oxidation mechanism put forward by Mohrbacher *et al*. [3] to explain the fretting wear of TiN coatings. The test temperature thus appears as an additional input of energy for crystallization of the debris, proportional to the test temperature increase.

4. References

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