COMPARATIVE STUDY OF FRETTING BEHAVIOURS OF HVOF-SPRAYED COATINGS AT ROOM AND HIGH TEMPERATURE

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Abstract

This paper provides a study of sliding wear behavior of Cr_3C_2-CoNiCrAlY thermally sprayed coating at room and high temperature - 600°C. Wear testing was realized by linearly reciprocating Ball-on-Flat sliding wear test according to ASTM G133-05, so called fretting test using the tribometer CETR-UMT3. The evaluation addresses specifically wear resistance, friction characteristic and sliding wear mechanisms. The coatings were examined by SEM imaging. The Cr_3C_2-CoNiCrAlY HVOF coating proved its potential as a coating for high temperature sliding or fretting application. Measured COF decreased together with increasing temperature. On the other hand, the wear resistance decreased at high temperature in the vicinity of oxide originated in the wear scar.

Keywords: Fretting, tribological properties, thermal spraying

1. INTRODUCTION

Thermal spraying is a technology of forming a functional surface coatings providing functional protection of coated parts. The high velocity oxy-fuel spray (HVOF) method allows to deposit hardmetal (cermet)-based coatings with high wear resistance and favorable sliding properties. These characteristics make HVOF sprayed coatings suitable for applications in conditions of sliding friction. [2] The evaluated Cr_3C_2-CoNiCrAlY coating is hardmetal coating characterized by a beneficial combination of hard carbides and a matrix, responsible for toughness.

One of the main causes of the fretting movement is vibration. It occurs not only in machinery, but in most industrial applications. The fretting loading can often lead to a critical component failure. That is why it needs to be studied in detail with respect to used materials and loading condition.

Fretting is a special case of fatigue wear at the surface. It can be tested by laboratory testing equipment, so called tribometers. Principle of method is the typically reciprocating sliding movement between two surfaces. In our case this method comprises two samples: a ball and a flat sample which is held reciprocating linear motion, while the bullet is loaded by a constant force. The load is applied vertically downwards through the ball on the sample which moves horizontally. Principle of the method is shown in **Fig. 1**. In the contact, the reciprocating friction load produces surface stresses that can result in cracks and fretting fatigue. [1] Fretting wear appears when the cracks at the surface results in wear particles. Then the released wear products stay for some period in the reciprocating contact and influence the contact conditions crucially, e.g. concentrating the surface load due to the releases wear particles and increasing the surface stresses under them. On steel surfaces, the contact process wears off the oxide layers on the surface, which is exposed to chemical reactions. Often the temperature is simultaneously increased, which

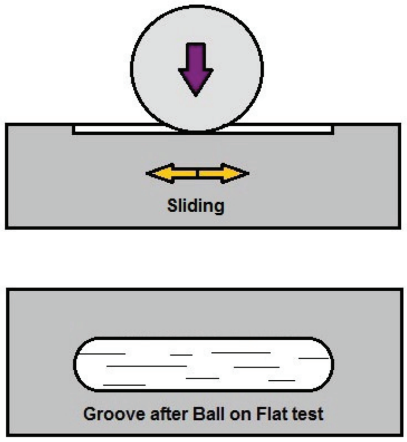

Fig. 1 Schematic diagram of the test ball-on-flat

speeds up chemical reactions [1]. These various phenomena occurring during sliding process for a ball-on-flat sliding contact are summarized in the **Fig. 2**.

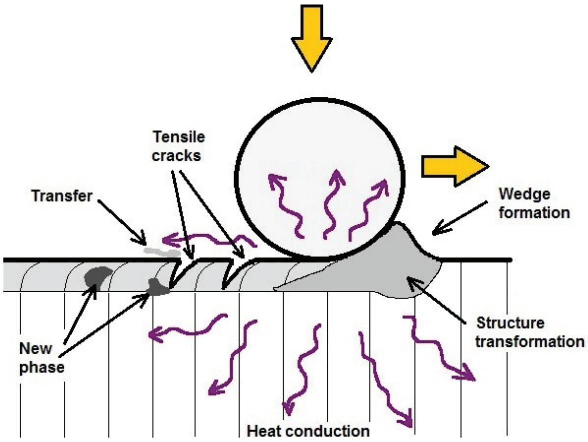

Fig. 2 Various phenomena occurring during sliding process for a ball-on-flat sliding contact [1]

2. EXPERIMENTAL PROCEDURE

The coated samples were deposited using HVOF (High Velocity Oxygen Fuel) thermal spraying technology TAFA JP-5000 in VZÚ Plzeň s.r.o. The deposition procedure, standardly used in VZÚ Plzeň for HVOF spraying, was applied. The spraying parameters were previously optimized to reach the low porosity and high hardness of Cr_3C_2-CoNiCrAlY coating [6]. As the substrate material, steel S355J0 was used.

Tribological measurements were performed using a standard test method for linearly reciprocating Ball-on-Flat sliding wear test without lubricant at room and high temperature according to ASTM G133-05. Following parameters were used: normal force: 25N, stroke length: 10 mm, oscillating frequency: 5 Hz, sliding distance: 100 m, counterpart: stainless steel AISI 440C and ambient temperature: 22 ± 3 °C and 600 ± 3 °C. Measurements were performed by tribometer CETR-UMT3 in the laboratories of NTC ZČU. During the measurement, the dependence of the sensed instantaneous Coefficient of Friction (COF) on the polished surface of the material against a piece of steel to the sliding track was scanned. The amount of wear was measured by a profilometer KLA-tencor P-6 Profiler. Data are arithmetic average of three measurements. Wear mechanisms was evaluated by a scanning electron microscope FEI QUANTA 200 with EDS detector EDAX NEW XL-30.

3. RESULTS AND DISCUSSION

The measured data describing the tribological characteristics were summarized for ASTM G133 in the graph (**Fig. 3**).

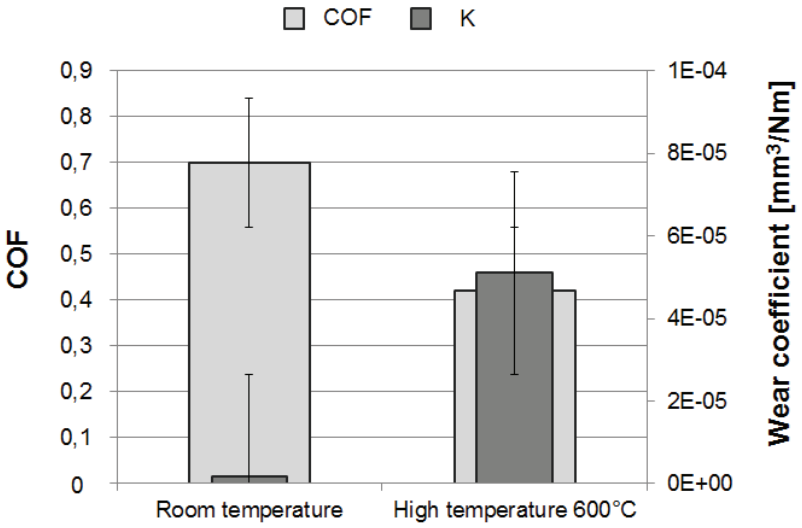

Fig. 3 Wear coefficient and COF measured by ball-on-flat oscillating test at a) room temperature and b) high temperature (600°C)

The results show that coefficient of friction at room temperature is higher than coefficient of friction at high temperature. Coefficient of friction at room temperature is 0.70 ± 0.04 and coefficient of friction at high temperature - 600°C is 0.42 ± 0.02. The running of the friction coefficient Ball-on-Flat wear test is shown in **Fig. 4**. The yellow, orange and green curve represents the COF values measured at wear test at room temperature. The second gray, blue and purple curve represents the COF values measured at wear test at high temperature - 600°C.

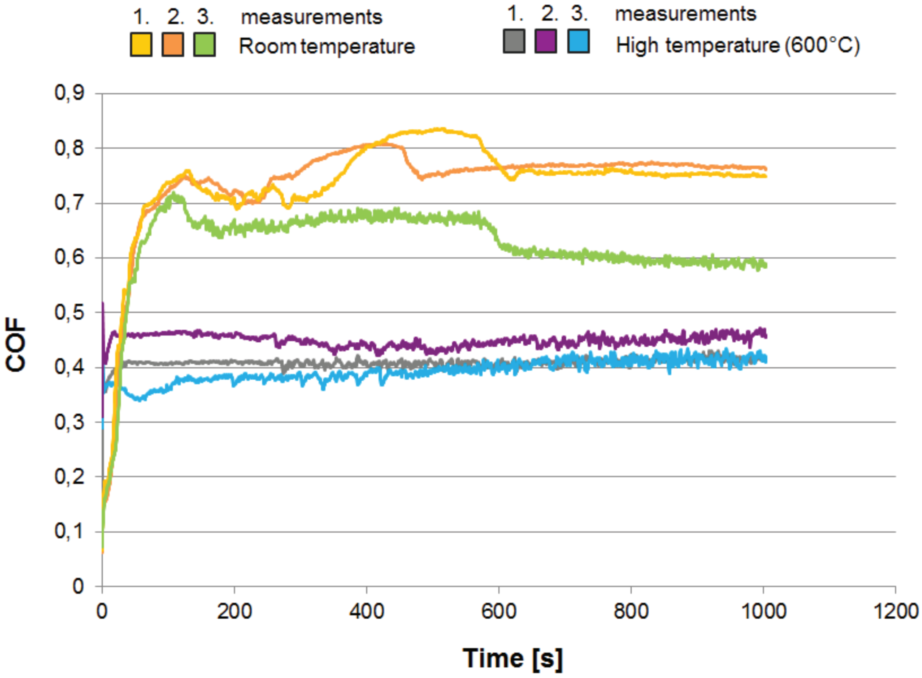

Fig. 4 Coefficient of friction measured by ball-on-flat oscillating test

The wear of the coating was expressed by wear coefficient K [mm^3/Nm], including the wear volume loss, used load and the wear distance. It was found, that he wear coefficient of the Cr_3C_2-CoNiCrAlY coating is significantly lower at room temperature compared to the wear at high temperature - 600°C: (1.70 ± 1) x 10^{-6} vs. (5.10 ± 0.2) x 10^{-5}.

In the [7], the phenomena of changing the phase composition from Cr-based carbides on to the ceramic oxides, under the circumstances of herzian loading and elevated temperature is described. The creation of chromium oxides in the wear track can be identified as a reason for COF decrease during high temperature wear testing. The same mechanism was previously described for another Cr_3C_2-NiCr HVOF coating [4].

On the other hand, the oxide layer can is probably more prone to wear off than the CrC carbide itself. The worn particles entrapped in the wear scar accelerate the wear and change the adhesive wear to the abrasive.

The presence of oxide was proved by the EDX. The elemental analysis showed the amount of oxygen on the surface of the groove after the Ball-on-Flat test (**Table 1**).

Table 1 Elemental composition at the groove after ball-on-flat test at high temperature

Element	C	Cr	Co	Ni	Al	Y	O
Wt %	4.51	58.64	9.39	9.58	4.29	0.63	12.95

The wear mechanism, observed by SEM, is shown in the **Fig. 5**. Typical wear mechanisms of HVOF hardmetal coatings is preferred gradual wear of the matrix, followed by reducing cohesion between the carbides and the matrix and the final releasing of carbide particles. In the case of dry friction the released carbide particles remain present in the sliding groove and serve as an abrasive, causing further wear. The wear mechanism is thus transformed from the adhesive to abrasive [3, 4]. In the **Fig. 6a, b** the area with a significant damage bottom loose carbides and deformed matrix can be observed. In [5], the wear mechanism of hardmetal coatings is described as a contact between the counterpart surface and protruding carbide-tipped indenters, which occur after a slight wear surrounding matrix. The bottom traces of wear on the test coating at high temperature - 600 °C exhibits a greater degree of damage are also signs of dissolved carbide with fatigue wear mechanisms. In the HVOF as-sprayed coatings wear scar the tribo-oxidation is identified (**Fig. 5c**). The oxide film cracks during further loading, taking part in wear process as abrasive medium.

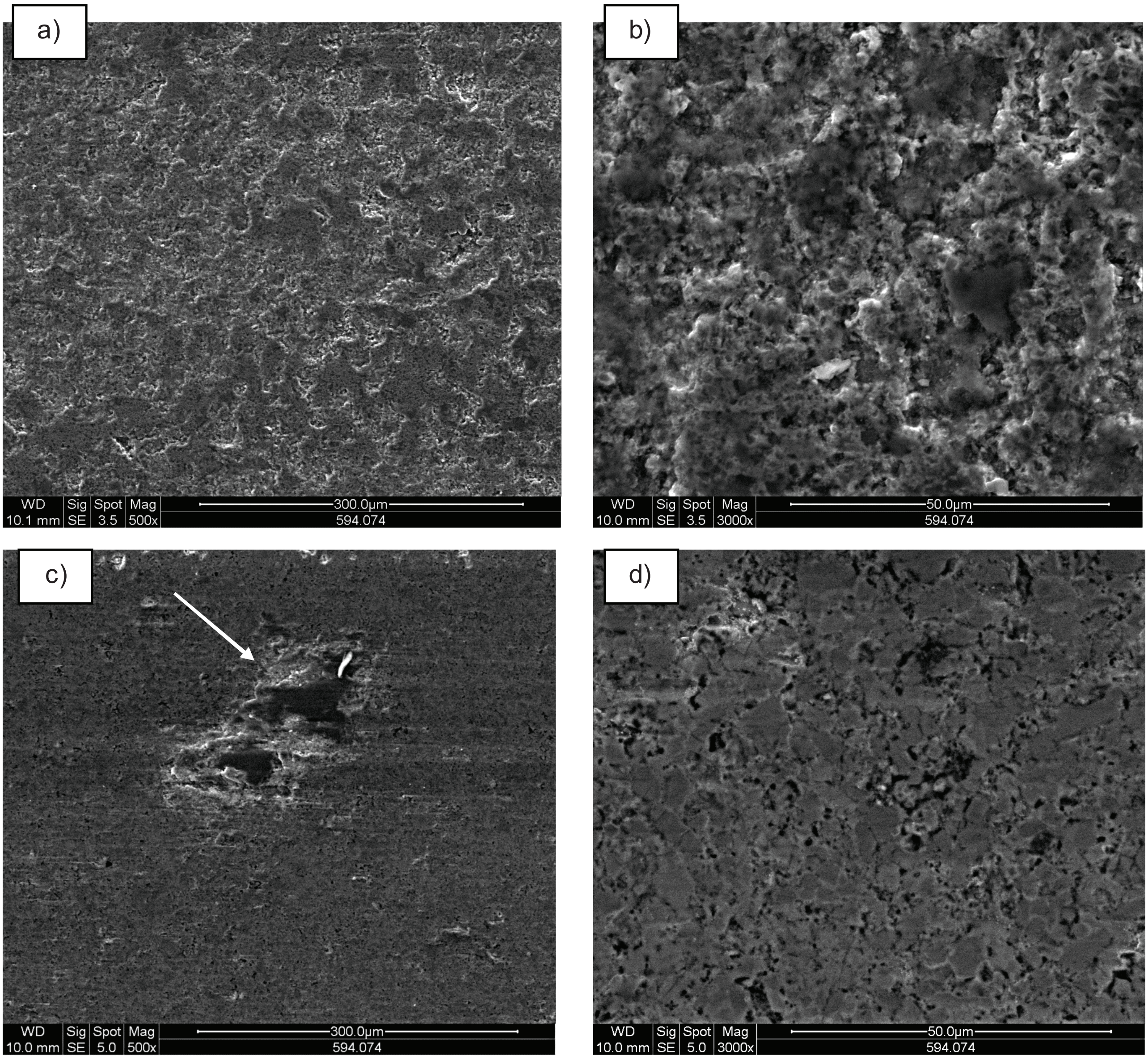

Fig. 5 Wear mechanism evaluated after ball-on-flat oscillating test at a), b) room temperature, c),d) high temperature (600°C)

4. CONCLUSION

Mapping behavior cermet thermal spray at fretting test Ball-on-Flat apparatus using tribometer CETR-UMT3 brings the following findings: the Cr_3C_2-CoNiCrAlY coating showed stable friction behavior combined with lower wear resistance at high temperature. The change of wear mechanism was connected with presence of oxygen in the wear groove. The combination of friction loading and elevated temperature led to the origin of chromium oxides, responsible for low COF but higher wear.

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