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High temperature tribological study of cobalt-based coatings reinforced with different percentages of alumina

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ABSTRACT

Contact surfaces, subjected to high pressure coupled with low-amplitude oscillation, are used to a great extent in aerospace engine components to reduce vibrations. Relative displacement of contact surfaces coupled with friction force dissipates energy and damps the vibrations. Fretting wear is harmful on interference-fit contacts because the loss of material reduces the normal load and hence, reduces their effectiveness in damping vibrations.

Coating is an important means to control friction and wear of contact surfaces. To address this issue an experimental layout was designed, and fretting wear tests were performed at high temperature (1000 °C). A representative sphere-flat contact was investigated in laboratory environment. Two types of metal-ceramic coatings, made of the same metal but with a different alumina percentage, were tested. Results were reported in terms of volume loss against number of wear cycles. It was found that increasing the alumina percentage was detrimental because the volume loss increased dramatically with high number of wear cycles. It was shown that wear results were strongly related to material properties, such as modulus of elasticity, while no correlation was found with contact parameters, friction coefficient and contact stiffness.

1. Introduction

In some aerospace components there are contact surfaces that undergo repeated cyclical rubbing with high pressure and small amplitude displacement known as fretting. Many times this is a design choice because during contact the energy dissipated, that is the product between friction force and displacements, reduces vibration amplitude, and consequently also stresses, in the component. Part of dissipated energy wears the component so that the contact surfaces are often coated with low wear rate material to prevent loss of materials. Materials with low wear rate often exhibit a low friction coefficient, and this undoubtedly reduces dissipated energy and damping capability. Thus, it is difficult to design coating materials with features that are so difficult to combine. In recent years, in order to respond to such high demands for wear resistance, materials engineers have been working to improve performance of coatings, developing new materials and coating methods. As it is of great interest to investigate tribological behavior of new contact materials in real operating conditions the demand for fretting wear experimental tests at high temperature is rising quickly. The work presented in this paper focuses on tribological properties of coatings applied to the Z-notch of shrouded blade. The shroud is a plate, usually located on the tip of the blade, in contact with shrouds of the contiguous blades. The Z-notch is specifically designed to maximize the damping effect as this is where the contact occurs. Similar devices applied in the middle of the blade, especially in the compressor section, are denoted mid-span dampers. Cobalt-based alloys reinforced with ceramics are widely used coatings on Z-notches in order to minimize damage due to fretting wear. These alloys exhibit low wear and high resistance to oxidation and thermal shock at high temperature. The tribological behavior of coatings is affected by several parameters such as (i) contact conditions – normal load, relative speed, surface morphology, (ii) environmental conditions – temperature, gases, lubrication – and (iii) contact materials, in terms of mechanical and chemical properties. Contact parameters, namely coefficient of friction and contact stiffness, and wear rate, cannot be accurately predicted solely through theoretical analysis, because of the complexity of the tribological contact mechanisms. An experimental campaign was carried out to evaluate the wear behavior of two types of cobalt-based coatings which differ in percentage of ceramic component (alumina) and deposition method. Moreover, contact parameters, that play a fundamental role in the dynamic behavior of mechanical components with contact joints, were measured continuously throughout the wear test.

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2. Materials

Coating materials were developed using multiple metal components, such as Co, Cr, Ta, Al and Y, blended with aluminum oxide Al_2O_3. The nominal chemical composition of CoCrTaAlY powder is given in Table 1. Three coatings were used in this study and they differ in alumina percentage and deposition method:

- "type A": 90% CoCrTaAlY + 10% Al_2O_3 in weight, deposited with detonation gun (D-gun);
- "type B": 90% CoCrTaAlY + 10% Al_2O_3 in weight, deposited with High Velocity Oxygen Fuel (HVOF);
- "type C": 70% CoCrTaAlY + 30% Al_2O_3 in weight, deposited with detonation gun.

The blended ceramic–metal, cermet, powder was thermally sprayed onto a prepared surface of specimens. The thermal spray led to a roughening of the surfaces: the measured roughness *Ra* ranged from 4–5 μm for type A, B and from 5–6 μm for type C coating. The thermal spray imparts a specific and characteristic topography, characterized by granular asperities with rounded edges, to the surface. The bulk material of the work piece was single crystal nickel superalloy (CMSX-4) and the thickness of the deposited coating was about 130 μm. The CMSX-4 bulk material was chosen because this was the same material as the aerospace component on which the coating is applied, even though the high thickness of coating should have made the results, from the tribological point of view, quite independent of the properties of the bulk material. After deposition the test specimens were subjected to a double heat treatment: a diffusion heat treatment, in order to enhance the adhesion to the substrate and an oxidation heat treatment, in order to improve the wear resistance. The surfaces were not machined after deposition and they were tested as-sprayed. The hardness differs little between the two types of coatings and micro-hardness measurements gave a value of 540 $HV_{0.3}$ at the interface and 470 $HV_{0.3}$ 50 μm beneath the interface.

3. Test procedures

Due to the great interest in investigating the tribological behavior of new coating materials in real operating conditions and the fact that the demand for fretting wear tests is rising quickly, two test rigs were developed in the laboratory AERMEC of the Department of Mechanical and Aerospace Engineering. These rigs carry out reciprocating wear and friction test with relative displacement of small amplitude. Both rigs [1,2] have the capability of performing fretting wear tests at high temperatures, up to 1000 °C, with a very accurate measurement of tangential force and relative displacement between contact surface, for the duration of the wear test. The first rig allows "point contact", the typical contact between two axisymmetric surfaces, while the second rig is able to bring into contact flat surfaces. In the latter, both mating surfaces are flat and a mechanism leaves one specimen free to tilt so that the initial geometrical contact takes place on three points and then, after the normal load is applied, contact occurs on the whole surface. For this investigation the point contact rig was preferred because results could be compared with previous test campaigns. The two specimens, shown in Fig. 1, rub against each other with a small amplitude oscillatory motion. One specimen has a flat contact surface, while the other has a hemispherical surface with radius of 25 mm. A schema of the test rig used in this campaign is depicted in Fig. 2. The "moving" specimen is attached to the center of a beam clamped at its ends. An electromagnetic shaker excites the beam in the center cross-section, in the same plane of the contact point. The moving specimen is conically shaped and is fitted in a conical hole in the support. The small angle of the conical fitting ensures a stiff and steady constrain between specimen and support. The "stationary" specimen, is conical shaped as well, and fitted in the conical hole of a mechanism. This mechanism consists of two rods connected to each other at a 90° angle. The two rods are hinged on top of two piezoelectric force transducers, which measure the tangential contact force opposing the relative motion. The normal load is applied to the mechanism by a system of pulleys and calibrated dead weights. An induction heating system, not shown in the schema of Fig. 2, was used because (i) it can reach high temperatures and (ii) its heating power can be concentrated on a small volume. A detailed description of the test apparatus, control software, procedure and accuracy of measurements is given in [3]. Two tribocouples, a contact pair made with one hemispherical and one flat surface, were coated with coating type A, two with coating type B and two with coating type C. Four tribocouples were formed with mixed coatings, type A on the flat surface, type B on the spherical surface (mix-1), and vice versa (mix-2). A constant normal contact load of 31.8 N was applied through

Table 1
Nominal composition of metal components of the coatings.

Coating	Element %						
	Co	Cr	Ta	Al	Y	Si	C
CoCrTaAlY	bal	21	8	11	0.6	0.6	1

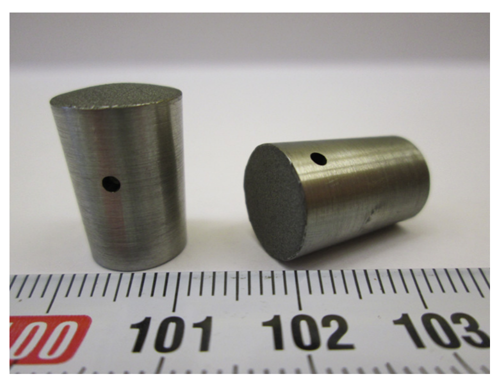

Fig. 1. A tribocouple used in the test campaign.

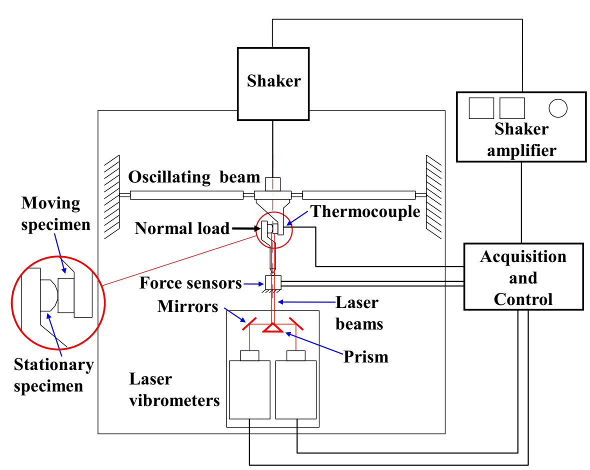

Fig. 2. Schema of the point contact test rig.