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Short communication

Development of a Wöhler-like approach to quantify the Ti(C_xN_y) coatings durability under oscillating sliding conditions

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Abstract

The selection of a proper material for the particular engineering application is a complex problem, as different materials offer unique properties and it is not possible to gather all useful characteristics in a single one. Hence, employment of different surface treatment processes is a widely used alternative solution. In many industrial applications, coating failure may be conducive to catastrophic consequences. Thus, to prevent the component damage it is essential to establish the coating endurance and indicate the safe running time of coated system. To this study PVD TiC, TiN and TiCN hard coatings have been selected and tested against polycrystalline alumina smooth ball. The series of fretting tests with reciprocating sliding at the frequency 5 Hz have been carried out under 50–150 N normal loads and under wide rage of constant as well as variable displacement amplitudes from 50 μm to 200 μm at a constant value of relative humidity of 50% at 296 K temperature. To quantify the loss of material a dissipated energy approach has been applied where the wear depth evolution is referred to the cumulative density of friction work dissipated during the test. Different dominant damage mechanisms have been indicated for the investigated hard coatings, which is debris formation and ejection in case of TiC coating and progressive wear accelerated by cracking phenomena in case of TiN and TiCN coatings. Energy–Wöhler wear chart has been introduced, in which the critical dissipated energy density corresponds to the moment when the substrate is reached after a given number of fretting cycles. Two different methods to determine the critical dissipated energy density are introduced and compared. The Energy–Wöhler approach has been employed not only to compare the global endurance of the investigated systems but also to compare the intrinsic wear properties of the coatings. It has been shown that the fretting wear process is accelerated by the stress-controlled spalling phenomenon below a critical residual thickness and a severe decohesion mechanism is activated. Finally the applicability of the investigated method to other coated systems subjected to wear under sliding conditions is discussed and analyzed. The perspectives of this new approach are elucidated.

Keywords: Wear; Carbide and nitride coatings; Coating endurance; Reciprocating sliding

1. Introduction

Degradation of surface layers in kinematic or static pairs due to wear is one of the principal industrial problems resulting in necessity of repairing or replacing mechanical components. Wear is a complex process and is considered as an interdisciplinary one in which different mechanical, physical, and chemical phenomena are involved. Fretting as a specific type of wear is defined as a small displacement amplitude oscillatory motion between two nominally motionless solid bodies in contact under normal load [1]. Depending on the fretting conditions (displacement amplitude, normal load) surface fatigue and/or surface wear induced by debris formation are progressing [2]. In a great part of mechanical applications the vibrations are being induced and the systems work under variable loading conditions. This in turn

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provokes degradation under oscillating sliding which leads to the failure of the elements. The devastation by fretting has been identified in rolling bearings, keys, riveted or screw joints, steel ropes, electric connectors, medical implants and is potentially dangerous for all kinds of transport vehicles.

Protection against fretting has to be taken into account at design stage of the nominally motionless junction. By designing an appropriate contact geometry of the junction, the concentration of stresses and consequently fatigue cracking can be avoided. Proper designing can also contribute to decrease of reciprocal displacement amplitude [3]. Nevertheless, destruction under oscillating sliding cannot be completely excluded as this kind of damage was reported even for displacement amplitudes less than 1 μm [4]. One of the effective methods of protecting against fretting wear is application of the appropriate surface engineering techniques. These can increase the tribological properties of the components by: inducing a residual compressive stress, decreasing the coefficient of friction, increasing the surface hardness and finally by controlling the surface chemistry [5–8].

Among different surface engineering techniques, the physical vapour deposition (PVD) and chemical vapour deposition (CVD) ones are the most widely used to mitigate the fretting wear rather than to improve the fretting fatigue strength. To enhance the resistance to fretting fatigue the treatments which are conducive to compressive residual stresses in the outer layer of the component are recommended [8], e.g. shot-peening, ion implantation, carburizing, nitriding or ion beam enhanced deposition. Nevertheless some preliminary results [9] show that hard PVD and CVD coatings can also improve the fretting fatigue strength of steels.

In numerous industrial applications, coating failure may be conducive to catastrophic consequences. Thus, to prevent the component damage, it is essential to establish the coating endurance and indicate the safe running time of the component. In fatigue investigations the lifetime of the specimen under uniaxial tension stress is often described in terms of useful and widely applied Wöhler's fatigue charts, which relate the number of cycles (N) to failure with maximal amplitude of cyclic stresses. The relevant Wöhler's graphs allow to establish the endurance limit of a material, i.e. the maximal tension value at which the specimen failure will not occur even after great number of cycles (i.e. from the range of 10^8–10^9 cycles or greater). The approach has been applied with success to study the fretting fatigue by adding the lateral loading pads to the classical fatigue rig [9–12]. This action takes immediate effect on the position of the Wöhler's curve and the influence of fretting fatigue can be expressed by the decrease of the endurance limit (Fig. 1).

Application of Wöhler's curves to compare different surface treatments under fretting wear regime was proposed by Langlade et al. [13]. However, the authors consider the endurance of a coating as a function of maximum pressure. The energy Wöhler-like concept introduced in this work appears more "universal" as the energy dissipated due to friction is a unique parameter that takes into account the crucial loading variables, which are the pressure, sliding distance and friction coefficient.

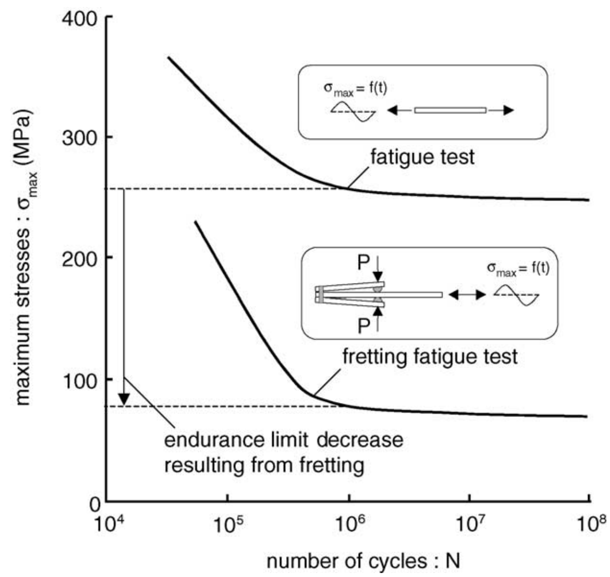

Fig. 1. Wöhler's curves for fatigue and fretting fatigue tests [12].

2. Experimental details

Fretting tests were carried out using an electrodynamic shaker activating a specific fretting rig (Fig. 2) manufactured by DeltaLab. Tests were carried out in a closed chamber where both the temperature and the relative humidity (RH) were controlled and kept constant: 50% RH at 296 K.

All the fretting wear experiments have been carried out under reciprocating sliding at the frequency (f) 5 Hz. Tests have been realised for the number of cycles starting from 1000 and usually less than 20,000 ones. A wide range of displacement amplitudes (50–200 μm) and normal loads (50–150 N) has

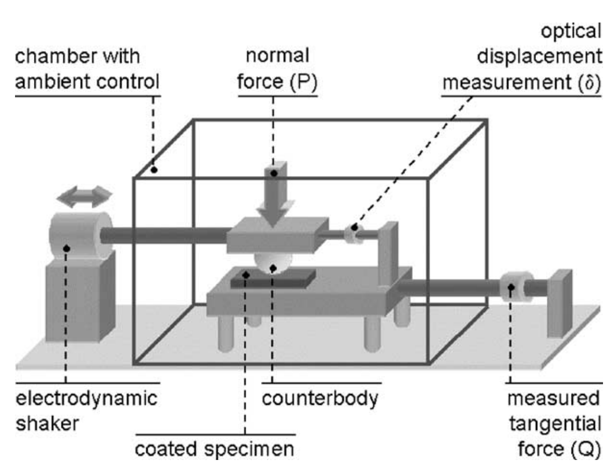

Fig. 2. Schematic of the fretting rig.