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Directional development of residual stress and surface fatigue during sliding contact

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ABSTRACT

Stresses in the near-surface area can form cracks which join together, propagate and combine, forming pits due to material spall-off. The stresses causing the cracks are not only influenced by external forces, residual stresses stored in the material also play an important role. Moreover, these residual stresses can vary during the lifetime of the sliding components. Cracks are found in the wear tracks of linear oscillating ball contacts on AISI 4140 steel. The crack propagation at the surface is longitudinal to the sliding direction. Residual stress analysis by X-ray diffraction (XRD) shows that normalized samples develop tensile stresses in the near-surface zone of the wear track. Residual stresses are found to be higher transversal to the moving direction than longitudinal.

1. Introduction

The relative motion of contacting bodies may not only damage the contact region of the surface through wear but also cause the surface to fail by cracking after exceeding critical residual stresses. One typical reason for material failure is stress concentration [1], often caused by external forces. Both, the stresses due to external loading and those already present in the material (residual stresses) have to be taken into account when studying crack evolution, i.e. residual stresses opposing those caused by external loading may act as protection since they lower the total stress in the component. Furthermore, knowledge of the residual stresses before tribological loading is insufficient for the interpretation of the damage process, since the residual stresses may evolve during the lifetime of machine parts [2]. When measuring the residual stresses by X-ray diffraction (XRD) it is important to consider the direction of the measurement in relation to the sliding direction since the introduced stresses are thought to be directional. The geometry of the counterpart and the moving direction should also be considered. When analyzing residual stresses in line contacts it is sufficient to consider only the direction longitudinal to the sliding direction [3]. For point contacts, the stresses transversal to the sliding direction are also of importance. In general, a stress field of compressive stresses runs ahead of the contact zone during sliding while a tensile stress field follows the contact [4]. In addition, the counterpart introduces Hertzian stresses into the material [5]. The alternating stresses can cause material changes such as generation and movement of dislocations [6], grain refinement, and phase changes [7], especially in combination with frictional heat.

The aim of this work is to analyze near-surface residual stresses by increasing the number of sliding cycles. Furthermore, the residual stresses prior to and after the defined cycles are analyzed by XRD-based stress determination methods regarding

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the damage development. Moreover, directional residual stress measurements were performed to get a better understanding of the crack propagation direction in the wear track. Together with modeled stresses of the elastic contact situation, the residual stresses measured are discussed regarding their influence on the damage mechanism.

2. Experimental

2.1. Investigated material

Tests were performed on constructional steel type 1.7225 (AISI 4140). Samples where cut out of an extruded rod (40 mm diameter) and afterwards grinded to a thickness of 10 mm. A pearlitic/ferritic microstructure (261 HV1) was obtained after normalizing the samples at 850 °C for 1 h and cooling in air (room temperature). Scale layers where removed by automated grinding followed by a finer grinding, achieving a surface roughness of Ra = 11.7 nm ± 1.6 nm. The roughness was measured using confocal profilometry (Nanofocus, μ-surf, 50×). The mechanical properties of the normalized 1.7225 steel are determined by [8] with a yield strength of 662 N/mm^2 and a tensile stress of 793 N/mm^2.

2.2. Tribological testing

The tests were performed using a linear oscillation test rig (SRV) [9,10] (see Fig. 1) with parameters according to Table 1. For tribological testing, a ball-on-plane geometry was used. Five different amounts of cycles were done within the sliding test. They were chosen with logarithmic progression (10, 100, 1.000, 10.000 and 100.000) in order to analyze different wear mechanism regimes.

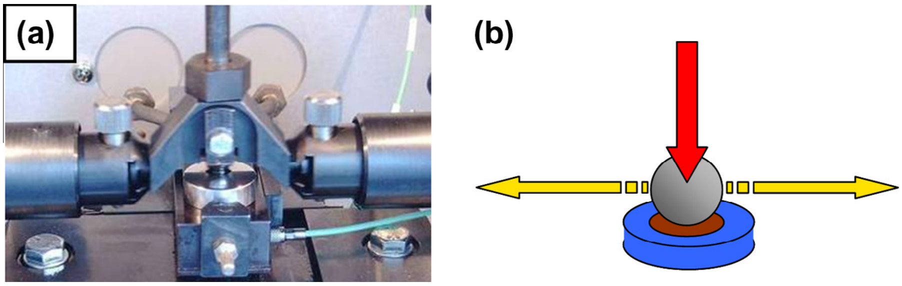

Fig. 1. (a) Linear oscillation test rig and (b) testing configuration.

Table 1
Parameters used in linear oscillation test rig.

Normal load	200 N
Stroke	2 mm
Frequency	50 Hz
Counterpart material	94% WC in 6% Co
Counterpart diameter	10 mm
Lubricant	FVA4 oil
Cycles	10, 100, 1000, 10.000, 100.000

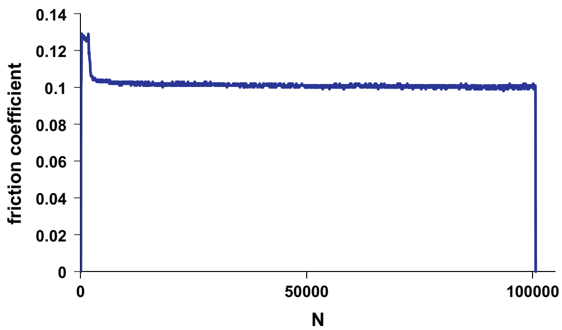

Fig. 2. Development of friction coefficient in dependence of testing cycles (10^5 cycles).