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A Study on Tribological Performance of Black Oxide Coating for Bearing Applications

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INTRODUCTION

The use of black oxide coatings (such as hot black oxidation layers [1, 2]) in bearing applications is widely discussed in industry. Black oxide is formed by a chemical reaction at the surface layer of bearing steel and is produced when parts are immersed in an alkaline aqueous salt solution at a temperature between 130 to 150°C. The result is a dark black surface oxide layer of approximately 1-2 µm in thickness.

A black oxide layer, compared to non-coated bearing steels, offers a number of benefits: it improves running-in behavior, increases corrosion resistance, repels chemical attack from aggressive lubricant additives, reduces hydrogen permeation, provides enhanced micropitting protection and improves smearing/scuffing resistance [3 - 8].

In the present study, it has been found that the right understanding of the different tribological factors that influence the efficiency of black oxide is a key to optimize the performance of the mechanical components. Therefore, a special focus is set on the tribological behavior of black oxidized surfaces in comparison with non-coated ones, with respect to micropitting protection, anti-smearing effects and some other important aspects like running-in. The results of the component laboratory experiments, full bearing tests and theoretical modelling performed within the frame of the present work, shed light upon the benefits and limitations of using black oxide coating for bearing applications.

RESULTS AND DISCUSSION

The experimental work performed in the present study is briefly summarized in Table 1 where all types of performed tests, employed test rigs, experimental conditions and results are described.

Based on the experimental results presented in Table 1, it can be concluded that black oxidization of at least the rougher component can optimize the tribological performance of a contact pair with a roughness differential. This should lead to a friction reduction and should therefore reduce the risks of micropitting and smearing. However, taking into account the other non-tribological beneficial effects of black oxide, like anti-corrosion effects and reduction in hydrogen permeation, black oxidation of both contacting components would become preferable.

Type of Test and Test Rig	Conditions	Result
Micropitting tests, PCS micropitting rig	Pressure 1.25-2.5GPa; slide/roll ratio 2%; roughness roller R_q=50nm; roughness rings R_q=450 to 1000nm; 0.72M load cycles; mineral base oil, boundary-to-mixed lubrication, black-oxidized or non-coated roller vs. non-coated rings.	Black-oxidized rollers showed better anti-micropitting performance than non-coated ones: micropitting developed under higher pressure or with higher roughness of the rings.
Friction and micropitting tests, WAM ball-on-disk rig	Pressure 2GPa; slide/roll ratio 5%; roughness ball R_q=20nm; roughness disks R_q=200nm; 3.9M load cycles; fully formulated engine oil, boundary-to-mixed lubrication, black-oxidized ball or non-coated vs. black-oxidized or non-coated disks (four possible combinations).	25% friction reduction after running-in and a much better anti-micropitting performance with black-oxidized disk (i.e. the rougher surface) vs. non-coated roller, in comparison with both non-coated.
Full bearing micropitting tests, FE8 rig	Cylindrical thrust roller bearings 81212, non-coated and black-oxidized, pressure 1.9GPa, speed 150rpm, FVA 2 base oil + 2% additive A, 27M load cycles.	Non-coated bearings were severely micropitted in the region of -2% slip on the rollers (not far away from the roller centerline). No micropitting was found for black-oxidized bearings under identical conditions.
Smearing tests, WAM ball-on-disk rig	Pressure 1.4GPa and 2GPa; various slide/roll ratios; roughness ball R_q=20nm; roughness disks R_q=100nm; mineral base oil, black-oxidized ball or non-coated vs. black-oxidized or non-coated disks (four possible combinations).	Enhanced anti-smearing performance when both the ball and the disk or only the rougher component (disk) is black-oxidized. No improvement in smearing performance with black-oxidized smoother component (ball) only.
Running-in tests with anti-wear additive, PCS micropitting rig	Pressure 1.5GPa; slide/roll ratio 2%; roughness roller R_q=50nm; roughness rings R_q=200nm; 20K, 50K, 100K load cycles; mineral base oil + 1% ZDDP additive, boundary-to-mixed lubrication, black-oxidized roller vs. non-coated rings, black-oxidized rings vs. non-coated roller, and both non-coated (3 cases in total).	Due to optimized running-in process, a better tribological performance in the steady state with black-oxidized rougher component (rings): 40% reduction in friction in the steady state in comparison with non-coated components. No performance improvement with black oxidized smoother component (roller) only.
Bearing Life tests, SKF R2 rigs	NU207 bearings; C/P=2.93; reduced film conditions, 300M revolutions, 10 fully black-oxidized bearings.	All the 10 black-oxidized bearings survived without failure. Identical non-coated bearings, tested in similar conditions, failed due to spalling

Table 1: *Summary of experiments – test rigs, experimental conditions and results.*

The theoretical part of the present work involves modelling of the micropitting failure mode for coated surfaces. The model (described in detail in [9]) assumes two rough surfaces in a loaded sliding/rolling contact with friction under mixed lubrication condition, where one or both surfaces have a surface layer of defined thickness with elastic properties –

Young's modulus and Poisson's ratio different than that of the bulk material. Moreover, due to the presence of this layer, the boundary-lubrication coefficient of friction may change.

The influence of three coating parameters on micropitting was evaluated, namely, the ratio of the Young's moduli, coating-to-bulk, the coefficient of boundary-lubrication friction and the coating thickness. It was found that the less stiff the coating is in comparison with the bulk material (i.e. the lower the Young's modulus of the coating), the better the anti-micropitting performance throughout the whole range of friction coefficients. This happens due to a more favorable distribution of subsurface stress with less stiff coatings. Also, a monotonous increase of micropitting with friction has been found (see discussion in [9]). Moreover, it was found that for coatings which are less stiff than the bulk material (e.g. black oxide) there exists an optimum thickness for minimizing micropitting development which, under simulated conditions, was about 2 µm, i.e. not far from the real thickness of black oxide.

CONCLUSION

By means of the experimental and theoretical results, it has been shown that the use of Black Oxide coating on the right (i.e. the rougher) component improves running-in behavior, provides enhanced micropitting protection and improves smearing/scuffing resistance. However, taking into account the other non-tribological benefits of black oxide, e.g. anti-corrosion effects and reduction in hydrogen permeation black oxidation of both contacting components may be preferable.

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KEYWORDS

Black Oxide Coating, Friction, Running-In, Wear, Rolling Contact Fatigue, Micropitting, Smearing