Investigation of the scuff resistance for plain bearings

Valery Alisin*

Mechanical Engineering Research Institute, Moscow, Russian Federation

Abstract. The article considers the issues associated with the evaluation of the scuff resistance of plain bearings with a iron-bronze friction couple OC 1-22. The statement that laser texturing of cast iron increases the antifriction properties of plain bearings is substantiated. The scuff behaviour of friction surfaces depending on the applied normal load are studied in comparison of surface nitriding and laser processing. The concept of increasing surfaces hardness based on hardening treatments is analyzed. As a result, it was found that laser heat treatment of surfaces is more effective in increasing the damage force rating. The process of changing the friction coefficient depending on the increase in pressure at the contact of tribological surfaces is being studied. The mechanics of the formation of scuffing of the surfaces under the conditions of boundary friction of a cast iron-bronze couple has been studied in relation to the operation of a cast-iron crankshaft of a heavy diesel engine. The method of analytical evaluation of the limit mode of friction on the load makes it possible to perform an approximate assessment of the effectiveness of measures to increase the expected life of a diesel engine.

1 Introduction

Scuffing of materials in the plain bearing leads to the cessation of the operation of the internal combustion engine. With regard to heavy diesel engines, the consequences of scuffing may require repair at the factory, so such accidents are associated with large economic losses. The tribological behaviour has a significant impact on the reliability and service life of engine crankshaft bearings. Along with studies of full-scale engines, modeling of the operation of bearings on laboratory friction machines is widely used [1]. The article analyzed in detail the test procedures and wear behavior, which noted the promise and adaptability to reproduce the accelerated wear of engine parts.

In the diagnostics of diesel operation, the main attention is paid to the study of used oil [2], the use of tribometric tests and surface analysis methods to assess the wear resistance of the engine, as well as the methods of acoustic emission [3] and vibration diagnostics. Methods for monitoring [4] and diagnosing malfunctions and wear of engines based on machine learning are being developed, including an artificial neural network model [5], Experiments are being carried out to evaluate the friction forces directly on the parts of a running engine [6]. It is shown that the experimental results of the friction force are in good

* Corresponding author: vva-imash@yandex.ru

agreement with the numerical results based on the model. A significant role belongs to research, aimed at optimizing the processes of diesel lubrication and the parameters of their operation, especially parametric studies of heavy diesel engines [7]. Analytical methods for describing thermal and gas-dynamic processes in heavy diesel engines are widely used [8-10], To improve the tribotechnical properties of friction couple in diesel engines, a variety of protective coatings are used. The work [11] shows the prospects of using functionally oriented coatings for marine diesel engine parts, especially when applying multilayer coatings with variable properties.

The purpose of the work is to investigate the mechanics of the formation of scuffing of surfaces under the conditions of boundary friction of a cast iron - bronze couple in relation to the operation of a cast-iron crankshaft of a diesel engine.

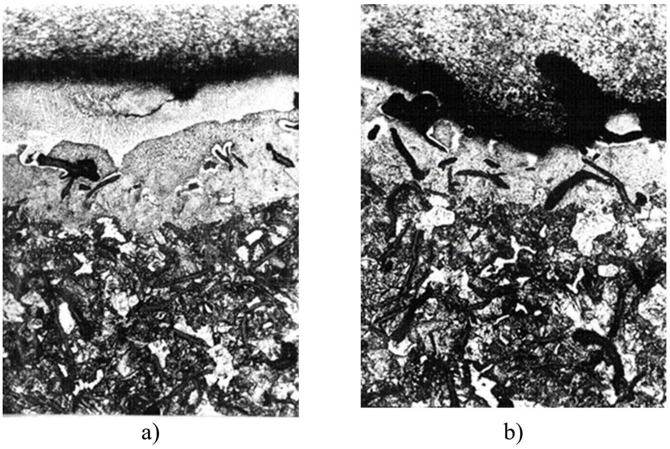
2 Materials and equipment

The crankshaft support is made in the form of a plain bearing, the neck journal of which is part of the crankshaft, made of AXHMM non-hardened cast iron, i.e. as delivered, nitrided and the bushing is made of OC-1-22 bronze. The experiments were carried out under conditions of boundary friction with M14F lubricant. The lower disk specimen rotated at n = 500 rpm, which corresponds to a linear velocity V = 3 m/s.

For experimental verification of the results of the theoretical analysis of the frictional engagement of tribological surfaces, specimens were made for tribological tests, which were treated using standard nitriding and experimental laser hardening technology. The specimens were cut from a full-scale cast-iron sleeve of a heavy diesel engine and treated with a CW laser to texturize the friction surface.

3 Results

The tribological properties of cast iron in the field of laser treatment strongly depend on the type of texturing of the heat-affected zone of the heat source, the lower the beam scanning speed, the higher the surface temperature. Experiments with laser surface treatment were carried out in the speed range 0.23 < v < 0.8 m/min. At a speed of 0.12 m/min, the largest amount of heat is supplied to the heat-affected zone from a given velocity range, which led to a large surface melting (Figure 1) and a large distortion of the surface roughness.



a) b)

Fig. 1. Structures of the surface layer: a) - melted surface; b) - not melted surface.

The melting of the surface of cast irons can lead to the formation of gas pores in the melt zone due to the release of gases during the crystallization of melts and a decrease in their solubility. To reduce the number of gas pores, additional technological measures are required, for example, alloying with magnesium, which has a deoxidizing effect, is advisable.

At the maximum speed of laser treatment, there is no surface melting, however, comparing the parameters of the heat-affected zone, we note a significant decrease in the geometric dimensions of the zone, which will lead to a significant decrease in the productivity of laser treatment. Currently, laser texturing of friction surfaces of ferrous metals is used to increase the expected life of plain bearings [12, 13]. For testing, the mode of laser treatment of surfaces on the fusion face was chosen, which corresponds to a scanning speed of the laser beam of 0.12 m/s. Figure 2 shows the structure of the surface layer corresponding to this regime.

Fig. 2. Laser hardening of the surface on the face of melting.

Scuffing is the most dangerous type of damage during boundary lubrication of friction joints in the conditions of start-stop of hydrodynamic bearings. A characteristic of the contact tension is the ratio of shear resistance to the yield limit of the base during shear, related to the properties of the surface layers. Shear resistance is not a constant, but depends on the actual pressure on the contact, which depends on the load, roughness, lubrication, mechanical properties of materials corresponding to a given speed limit and other friction conditions. Since it has now been established that the strength of molecular bonds in the tangential direction is described by the binomial law of friction, it is of practical interest to consider the case when the frictional interaction on the areas of actual contact of real bodies is described by the binomial Coulomb law.

$$\tau = \tau_0 + \beta p_r \tag{1}$$

For τ_n, σ_n we have:

$$\tau_n = k\cos 2(\varphi - \theta)\,, \sigma_n = 2k\varpi - k\sin 2(\varphi - \theta) \tag{2}$$

where φ - is the angle between the vertical radius drawn to the current point; θ - the angle of inclination of the characteristics of the second family to the abscissa axis. At θ=0 sticking of the half-space material onto the indenter will occur. Let's denote $\lambda = arctg\beta$.

Substitute (2) into (1) and solve for θ

$$\theta = -\frac{1}{2}\langle \cos ec\lambda - \cos[2(\theta-\varphi)+\lambda] - \frac{\tau_0}{k\beta}\rangle - c\,. \tag{3}$$

The constant (c) is determined from the boundary conditions. On the free boundary of the half-space we have: σ_x =0, τ_{xy} =0.

Considering that the fluidity condition is

$$(\sigma_x - \sigma_y) + 4\tau_{xy} = 4k^2$$

We get: $\sigma_x = -2k$.

Since $\varpi = \frac{1}{4k}(\sigma_x + \sigma_y)$ and $\theta = \frac{\pi}{4}$ we will have C=$\omega + \theta = 1.285$

Formula (3) is inconvenient for use, therefore we solve it relatively φ and setting 0< $\theta < \frac{\pi}{4}$, we build a graphical dependence $\theta = \theta(\varphi)$, then we approximate it with a linear dependence of the form $\theta = A\varphi - B$.

The position of the point corresponding to the transition from plastic pushing to microcutting and determining the threshold of external friction is characterized by the coordinate φ_0 . Setting θ=0, we solve (2,3) related to φ , then

$$\varphi_0 = \frac{1}{2}[\pi + \lambda - \arccos(2\sin\lambda - \frac{\tau_0}{k}\cos\lambda)] .$$

The section $\varphi_0 < \varphi < \frac{\pi}{2}$ corresponds to slippage.

From geometric considerations φ=arcsin(1-h/r), then the limit value of penetration (h_{max}) at which the microcutting mode occurs.

$$\frac{\text{hmax}}{r} = 1 - sin1/2[\pi + \lambda - \arccos\left(2sin\lambda - \frac{\tau_0}{k}cos\lambda\right)]. \tag{4}$$

For the case of multiple contact (friction of surfaces) we determine the critical value of the contact pressure at which microcutting occurs. To do this, in the expression (4), we substitute the dependence of the approach (h of rough surfaces on pressure (p)

$$h = \frac{Rmax}{b^{1/\nu}}(\frac{p}{\rho r})^{1/\nu} ,$$

where: R_{max} – is the maximum height of the roughness profile;

b and ν - parameters of the main roughness curve;

p_r - actual contact pressure.

Then:

$$\rho_c = \frac{\rho r}{\nu}\{1 - sin1/2[\pi + \lambda - \arccos\left(2sin\lambda - \frac{\tau_0}{k}cos\lambda\right)]\}^{\nu}, \tag{5}$$

where $\frac{Rmax}{rb^{1/\nu}}$ - complex characteristic of roughness; k - shear yield limit.

Let us analyze the effectiveness of laser treatment for the resistance to scuffing of surfaces under equal friction conditions, in which the effect of the temperature resistance of the lubricating layer on scuffing is the same in the first approximation. In this case, we will assume that the main factor determining the magnitude of the critical approach of the surfaces at which scuff occurs is the microhardness of the surface layer. The parameters τ_0 and β characterizing the shear strength of molecular bonds in the zones of actual contact remain unchanged for given materials of the friction couple, hardening treatment and type of lubricant, the method for their determination is standardized (GOST 27640-88).

Thus, a refined condition for scuffing surfaces under external friction, in which the parameter ρ_c is a function of the parameter k is obtained. On the basis of formula (5) it seems possible to predict the effect on scuff resistance of a change in surface roughness in terms of the parameters $\frac{Rmax}{rb^{1/\nu}}$ and ν, as well as the effect of lubricant grades. Figure 3 shows the results of the experiments.

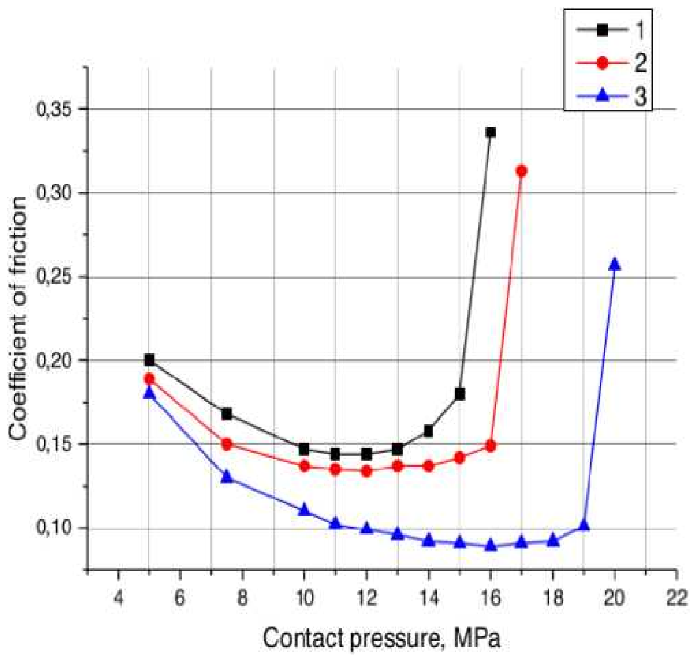


Fig. 3. Contact pressure effect on the friction coefficient in a steel-bronze friction couple OHC- 1-22: row 1 - initial state; row 2 - nitriding; row 3 - laser hardening.

The scuff resistance of laser-hardened surfaces exceeds the scuff resistance of nitrided surfaces by 1.2 times. The critical pressure p was calculated from the surface microhardness for the case:

$$p_c = 1\ \text{kgf/mm}^2;\ \beta = 0{,}08;\ h = \frac{Rmax}{b^{1/\nu}} = 0{,}05;\ \nu = 2.$$

An increase in the surface microhardness from H_{200} = 321 kgf/mm^2 to H_{200} = 840 kgf/mm^2, achieved after laser treatment, leads to an increase in the critical contact pressure of 1.3 times compared to the scuff resistance of an unhardened surface, which is in satisfactory agreement with the calculation.

4 Conclusions

The mechanics of surfaces scuffing formation under the conditions of boundary friction of a cast iron-bronze couple has been studied in relation to the operation of a heavy diesel engine cast iron crankshaft.

The laser hardening of cast iron crankshaft journals is more effective in terms of scuff resistance and antifriction than nitriding. The effect of transition from nitriding to laser texturing of the friction surface of cast iron is at least 20% according to the scuff resistance criterion.

The proposed method for the analytical evaluation of the limit mode of friction on the load makes it possible to carry out an approximate assessment of the effectiveness measures to increase the expected life of a diesel engine.

References

1. L.I. Farfan-Cabrera, E.A. Gallardo-Hernandez, Wear **376-377(Part B)**, 1841-1848 (2017). https://doi.org/10.1016/j.wear.2016.11.049
2. T. Kirkby, J.J. Smith, J. Berryman, M. Fowell, T. Reddyhoff, Wear **524-525**, 204733 (2023). https://doi.org/10.1016/j.wear.2023.204733
3. X.T. Dong, M.H. Nguyen, D. Lee, Measurement **162**, 107907 (2020). https://doi.org/10.1016/j.measurement.2020.107907
4. X. Rao, C. Sheng, Z. Guo, C. Yuan, Mechanical Systems and Signal Processing **165**, 108385 (2022). https://doi.org/10.1016/j.ymssp.2021.108385
5. X. Xu, Z. Zhao, X. Xu, J. Yang, L. Chang, X. Yan, G. Wang, Knowledge-Based Systems **190**, 105324 (2020). https://doi.org/10.1016/j.knosys.2019.105324
6. R. Li, C. Wen, X. Meng, Y. Xie, Applied Ocean Research **121**, 103089 (2022). https://doi.org/10.1016/j.apor.2022.103089
7. D. Lu, G. Theotokatos, J. Zhang, H. Zeng, K. Cui, Applied Thermal Engineering **200**, 117654 (2022). https://doi.org/10.1016/j.applthermaleng.2021.117654
8. S. Liu, Y. Cui, Y. Fu, B. Li, B. Lv, Y. Qian, Tribology International **165**, 107244 (2022). https://doi.org/10.1016/j.triboint.2021.107244
9. R. Wang, H. Chen, C. Guan, W. Gong, Z. Zhang, Applied Ocean Research **112**, 102681 (2021). https://doi.org/10.1016/j.apor.2021.102681
10. A. Sanchez-Herguedas, A. Mena-Nieto, F. Rodrigo-Munoz, Reliability Engineering & System Safety **207**, 107394 (2021). https://doi.org/10.1016/j.ress.2020.107394
11. A.V. Kostenko, A.N. Mikhaylov, A.V. Lukichov, Materials Today: Proceedings **38(4)**, 1789-1793 (2021). https://doi.org/10.1016/j.matpr.2020.08.277
12. G. Laki, A. L. Nagy, J. Rohde-Brandenburger, B. Hanula, Tribology Online **17(4)**, 318-334 (2022). https://doi.org/10.2474/trol.17.318
13. Z. Wang, R. Ye, J. Xiang, Tribology International **177**, 108010 (2023). https://doi.org/10.1016/j.triboint.2022.108010