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Influence of the roughness on surface geometry of rolling contacts

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Abstract. The topography of the active surfaces in rolling contact depends on the surface roughness obtained by different manufacturing process technology (turning, grinding, polishing, lapping, etc.). The aim of this paper work is to evidence the influence of the surface roughness on surface geometry of rolling contacts. The experimental tests were carried out on the AMSLER machine and an experimental setup for pure rolling motion. The surfaces of the rolling samples were analyzed with SEM (scanning electron microscopy) and EDS (energy dispersive X-ray spectroscopy) techniques for structural and chemical analysis and measured with the Taylor Hobson profilometer before and after the experimental tests for surface topography.

1. Introduction

The topography of the active surfaces in rolling contact depends on the surface manufacturing process technology. In the field of engineering the exact degree of roughness can be of considerable importance, affecting the function of a component or its cost [1, 2]. The presence of nano-asperities on contact surfaces influence the running-in process of important machine parts [3], such as rolling bearings, gears, cam-cam followers unit, wheel-rail subassembly, etc.

The roughness of the surfaces that interacts has an important role on its tribological behaviour. The solutions of the models used in order to describe it [4, 5] require the input of a three-dimensional rough profile. Since the experimental acquisition of such profiles it does not allow a sufficiently large sample of profiles to be used, an essential requirement for any numerical algorithm is to generate arbitrarily rough surfaces with the same or similar proprieties of the real surfaces [6, 7].

When two engineering surfaces are loaded for the first time changes in the topography of both surfaces generally occur. These changes appear between start-up and steady state and are associated with running-in process [8, 9].

An analysis model was used to model the nonlinear strain rate dependent deformation of materials stressed in elastic-plastic domain [10, 11]. The model is developed in the frame of incremental theory of plasticity using the von Mises yield criterion and Prandtl-Reuss equations. Considering the isotropic and non-linear kinematic hardening laws of Lemaitre-Chaboche [12, 13] the model accounts for the cyclic hardening phenomena. The cyclic evaluation process of both the plastic strains and residual stresses is performed until the material shakedowns [10, 11].

Recently, to characterize the chemical and structural modifications of superficial layer on the atomic or molecular level of materials, many researchers use different techniques such as X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDS), transmission electron microscopy (TEM) or scanning electron microscopy (SEM), [14, 15]. In this paper we used SEM and EDS techniques for structural and chemical analysis of the rollers surface before and after experimental tests.

2. Experimental setup

To evaluate the running-in process and the surface roughness modification for the case of two steel rollers, were carried out experimental tests on two rollers machine (AMSLER), figure 1.

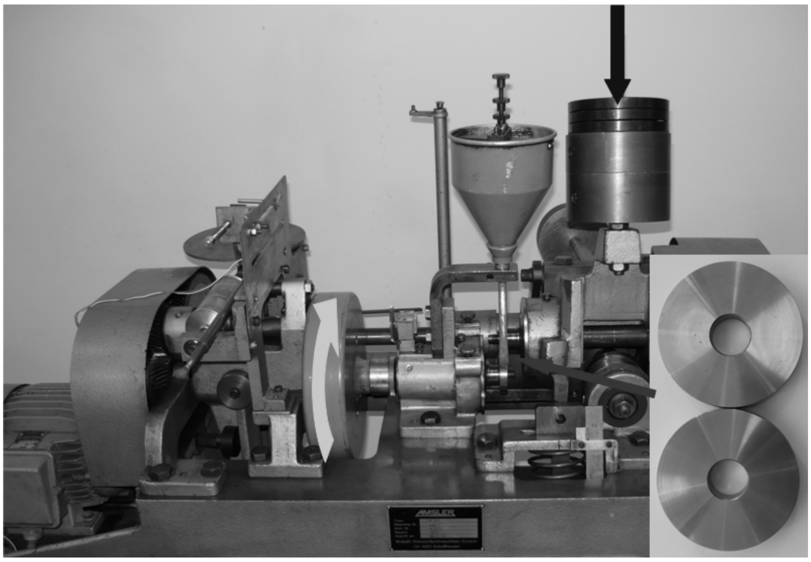


Figure 1. The AMSLER machine.

The two rollers running against each other with different rotational speed, having the constant rotational speed ratio $k = n_2/n_1 = 0.906$, where n_1 and n_2 are rotational speed of the lower and upper roller respectively. The slide-to-roll ratio ξ is determined by the following relation:

$$\xi = \frac{2 \cdot (v_1 - v_2)}{v_1 + v_2} = 2 \cdot \frac{(1 - k \cdot D_2 / D_1)}{(1 + k \cdot D_2 / D_1)} \tag{1}$$

where D_1 and D_2 are the lower and upper roller diameters, respectively.

Two rollers with diameters of *53.5 mm* and *59 mm* made from 42CrMo4 steel were used for pure rolling motion ($\xi = 0$). The lower roller with diameter of *53.5 mm* it is cylindrical and the upper roller with diameter of *59 mm* it is crowned with radius of *300 mm*, both rollers have *10 mm* in length.

Testing conditions: normal load $F = 140\ N$, rotational speed test $n_1 = 181\ rpm$ and running time *10 min*.

3. Numerical rough surface generation

Every surface has some form of texture topography which varies according to its structure and the way it has been manufactured. According to [2] there are three categories of roughness profile parameters: amplitude parameters (the vertical characteristics of the surface deviations), spacing parameters (the horizontal characteristics of the surface deviations) and hybrid parameters. Definition of all roughness parameters are given in ISO standards [16, 17]. The most used roughness parameters in technical drawing sheets for a given workpiece are R_a (arithmetic mean height) or R_z (mean height for the five highest peaks and the five lower valleys from roughness profile); i. e. of other amplitude parameters: R_q - root mean square deviation, R_t - the maximum peak to valley height.

It was developed a numerical method for the generation of arbitrarily defined three-dimensional rough surface, [18]. The surface roughness heights can be generated according to the following relation:

$$z_{ij} = \sum_{k=1}^{n} \sum_{l=1}^{m} \alpha_{kl} \cdot \eta_{i+k,j+l} \tag{2}$$

where α_{kl} are coefficients that provide the desired autocorrelation function and $\eta_{i+k,j+l}$ are independent random numbers and have unit variance [6, 18].

$$E(\eta_{ij}\eta_{kl}) = \begin{Bmatrix} 1 \text{ if } & i = k, j = l \\ 0 \text{ if } & i \neq k, j \neq l \end{Bmatrix} \tag{3}$$

Using eqs. (3) the autocorrelation function is obtained as:

$$R_{pq} = \sum_{k=1}^{n-p} \sum_{l=1}^{m-q} \alpha_{kl} \cdot \alpha_{k+p,l+q} \tag{4}$$

Eqs. (4) represent a non-linear system of *nxm* equations with the coefficients α_{kl} as unknowns, [6]. An iterative technique has been used to solve the non-linear equations system (4) and the obtained solutions were used further in eq. (2) to obtain the roughness heights with the desired autocorrelation function.

When two rough surfaces are into contact it can be generated an equivalent rough surface [18], obtained by summing corresponding values of the roughness heights:

$$z = z_1 + z_2 \tag{5}$$

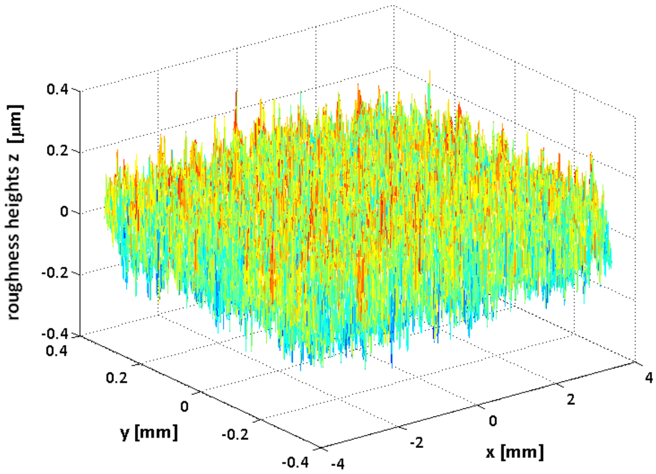


Figure 2. Arbitrarily generated rough surface [6, 18].

4. Experimental and numerical results

For structural and chemical analysis of the rollers surface before and after experimental tests it was used the scanning electron microscope with EDAX detector. In figure 3 is presented a typical EDS spectrum obtained for D_2 surface roller after experimental test.

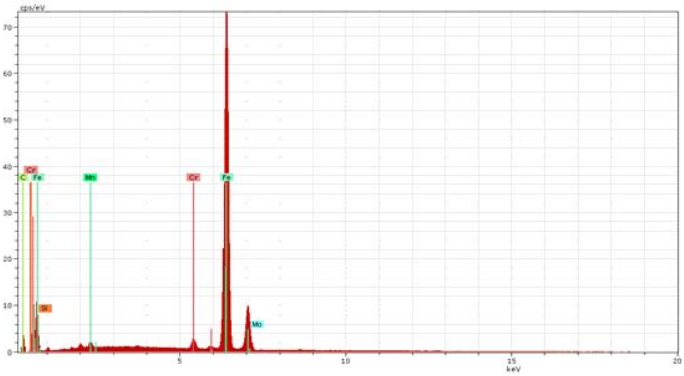
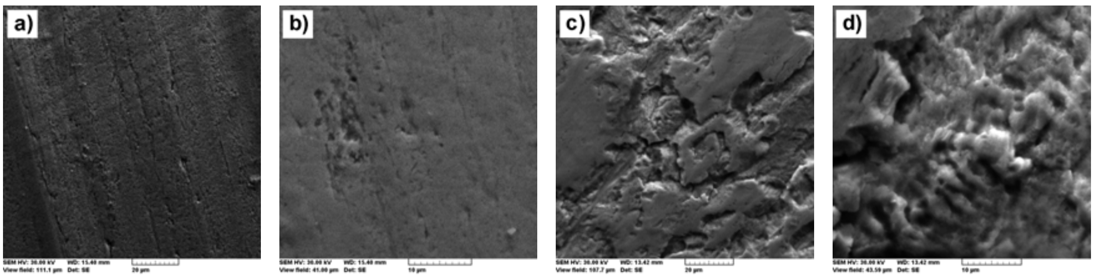


Figure 3. EDS spectrum for D_2 roller.



2000x 5000x 2000x 5000x

Figure 4. Surface SEM images after experimental test: D_2 roller (a, b) and D_1 roller (c, d).

Figure 4 shows microstructure of the running-in track into the rollers surface after tests on AMSLER machine, were can be observed a smoother surface for the upper roller D_2 with minor changes and a grossly rough surface for the lower roller D_1 with the flattened roughness peaks due to the rolling process.

Table 1. Chemical composition of the running-in track into the rollers surface (wt. %).

42CrMo4 steel rollers	Si	Mn	Cr	Mo	C	Fe
D_1 before	*0.385*	*0.891*	*1.199*	*0.298*	*0.415*	*balance*
D_1 after	*0.378*	*0.909*	*1.218*	*0.305*	*0.421*	*balance*
D_2 before	*0.386*	*0.889*	*1.198*	*0.299*	*0.418*	*balance*
D_2 after	*0.391*	*0.872*	*1.188*	*0.287*	*0.409*	*balance*

Table 1 presents the EDS results, showing the minor changes in the atomic composition of the running-in track into the rollers surface. These were measured before and after the rolling tests on AMSLER machine.

In figure 5 are presented the roughness profiles for the two rollers tested on the AMSLER machine, before and after the running test. The initial roughness of the rollers was $R_{a1} = 460\ nm$ and $R_{a2} = 220\ nm$, respectively $R_{q1} = 610\ nm$ and $R_{q2} = 280\ nm$.

The measurements of the rollers roughness before and after the tests evidenced that important modifications were produced for the lower roller, with a grossly roughness, for the approximate length of *1 mm* in the contact area. After the running test the average roughness height of the lower roller decreases to $R_{a1} = 390\ nm$ and root mean square deviation to $R_{q1} = 550\ nm$.

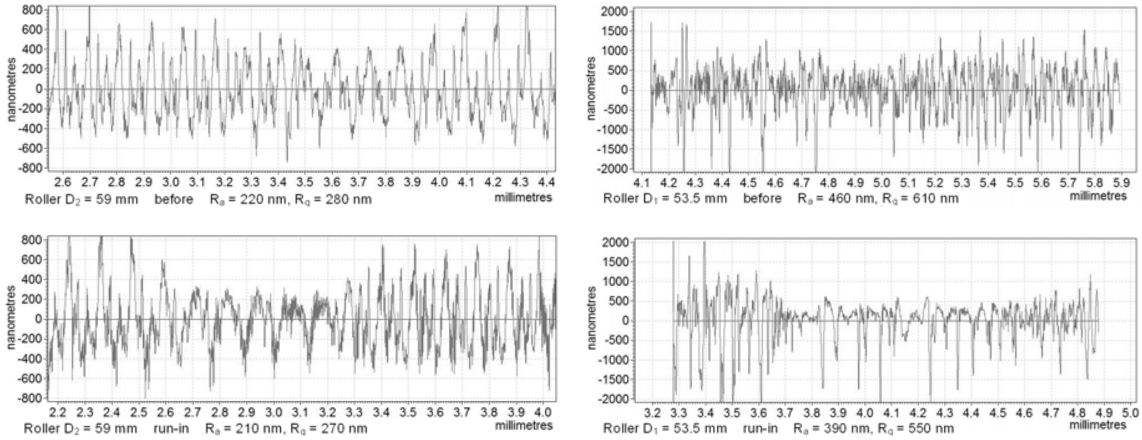


Figure 5. Experimental 2D roughness profiles before and after running test.

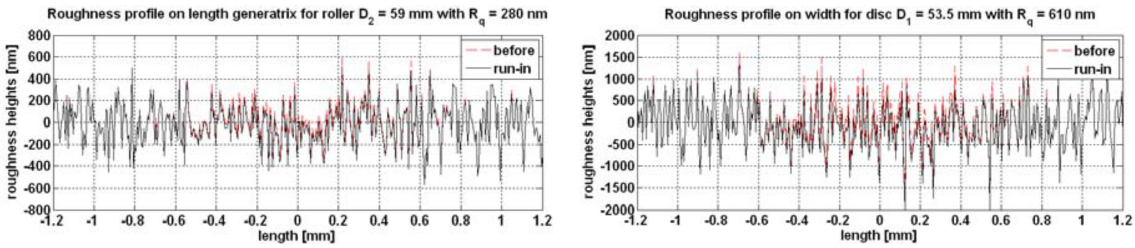


Figure 6. Numerical 2D roughness profiles before and after *300* running cycles.

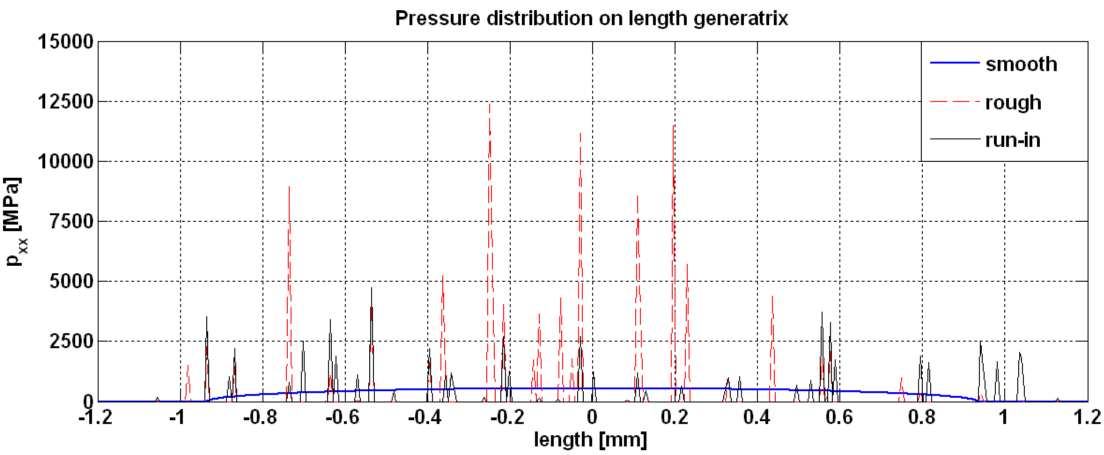


Figure 7. Pressure distribution on length generatrix of the rollers.

The same tendency was also observed with the elastic-plastic model after *300* running cycles, figure 6. The numerical results are in very good concordance with experimental test and with numerical results provided by running-in model presented in [8, 9].

The plastic modification of the surface roughness is given by the fact that the nano-asperities on the surface generates high peaks in the pressure distribution on the contact area between the two rollers, figure 7, pressure peaks which are a few times higher than the yield limit and locally produces plastic deformation of the nano-asperities. Also, if the surfaces will have a grossly roughness the changes will be more pronounced than for the surfaces with finer roughness and will diminish the higher peaks from the pressure distribution.

5. Conclusions

The topography of the active surfaces in rolling contact depends on the surface manufacturing process technology. Experimental and numerical results presented in this paper evidence the fact that the presence of nano-asperities on contact surfaces influence the running-in process and durability of a given application [3].

It was used a numerical method to generate an arbitrarily defined three-dimensional rough surface and an elastic-plastic model to take into account the running-in process.

The experimental results obtained on AMSLER machine present a very good concordance with the numerical results for two rollers case and with numerical results provided by running-in model presented in [8, 19].

The presence of nano-asperities on contact surfaces generates peaks in pressure distributions, higher peaks for surfaces with grossly roughness. For surfaces with grossly roughness the running-in process is more pronounced than for surfaces with a finer roughness.

6. References

[1] Robbe-Valloire F 2001 Statistical analysis of asperities on a rough surface *Wear* **249** pp 401-408
[2] Taylor Hobson Precision 2003 *Exploring surface texture* (TH Ltd)
[3] Stawicki T, Sedlak P, Koniuszy A 2010 The testing of the influence of the roughness of the crankshaft journal upon the durability of the crankshaft bearing in engines of agricultural machines *Sci. probl. of mach. op. and maint.* **4** pp 7-17
[4] Allwood J, Ciftci H 2005 An incremental solution method for rough contact problems *Wear* **258** pp 1601-1615
[5] Allwood J 2005 Survey and performance assessment of solution methods for elastic rough contact problems *J. Tribol.* **127** pp 10-23
[6] Bakolas V 2003 Numerical generation of arbitrarily oriented non-gaussian three-dimensional rough surfaces *Wear* **254** pp 546-554
[7] Patrikar RM 2004 Modeling and simulation of surface roughness *App. Surf. Sci.* **228** pp 213-220
[8] Jamari J 2006 *Running-in of rolling contacts* (PhD Thesis Twente)
[9] Jamari J, de Rooij MB and Schipper DJ 2007 Plastic deterministic contact of rough surfaces J. *Tribol.* **129** pp 957-962
[10] Benchea M, Iovan-Dragomir A, Creţu S 2014 Misalignment effects in cylindrical roller bearings *App. Mech. and Mat.* **658** pp 277-282
[11] Creţu S, Benchea M, Iovan-Dragomir A 2016 On basic reference rating life of cylindrical roller bearings. Part II - Elastic-Plastic Analysis *J. Balk. Tribol. Assoc.* **22/1** pp 272-280
[12] Chaboche JL 2008 A review of some plasticity and viscoplasticity constitutive theories *Int. J. Plasticity* **24** pp 1642-1693
[13] Besson J, Cailletaud G, Chaboche JL, Forest S and Blétry M 2010 *Non-linear mechanics of materials* (Springer)
[14] Guo T, Kong C, Li X, Guo P, Wang Z, Wang A 2017 Microstructure and mechanical properties of Ti/Al co-doped DLC films: Dependence on sputtering current, source gas, and substrate bias *App. Surf. Sci.* **410** pp 51-59
[15] Yuan Y, Li Z 2017 Microstructure and tribology behaviors of in-situ WC/Fe carbide coating fabricated by plasma transferred arc metallurgic reaction *App. Surf. Sci.* **423** pp 13-24
[16] ISO 4287:1996, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters
[17] ISO 4288:1996, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Rules and procedures for the assessment of surface texture
[18] Creţu S 2009 *Elastic-plastic concentrated contact* (Politehnium)
[19] Jamari J, Schipper DJ 2007 Deformation due to contact between a rough surface and a smooth ball *Wear* **262** pp 138-145