About four balls scuffing test parameters

C Hangan¹, C Românu and I Muscă¹

¹Mechanics and Technologies Department, Mechanical Engineering, Mechatronics and Management Faculty, “Ștefan cel Mare” University, Suceava, Romania

E-mail: catalin.hangan@yahoo.com

Abstract. The paper aims to contribute to the understanding of scuffing occurrence. The evolution of surface topography during four balls test using two types of grease was investigated. For testing, a four balls experimental setup was used. The test rig allows loading the contact between balls while maintaining relative motion between surfaces. Constant velocity is maintained for 10 seconds as per the EN ISO 20623:2003 procedure. The wear scar produced during testing was investigated by means of an optical 3D profilometer and the roughness parameters were analysed. Experimental results reveal that the values of arithmetical mean height $S_a$ and root mean square height $S_q$, have a significant growth and they are correlated with the occurrence of the scuffing phenomenon.

1. Introduction

One of the most important causes of joints failure is the occurrence of scuffing. To predict the scuffing phenomenon, several tests were developed during time. The literature presents specific tests in order to evaluate the contact loading capacity, lubricants quality and contact reliability. Some of those tests were generalized and became International Standard. One of those standards is EN ISO 20623:2003 [1]. This standard specifies the testing procedure for measuring the extreme pressure and anti-wear properties of lubricants using a four balls machine.

A previous research revealed that the contact wear scar obtained using EN ISO 20623:2003 procedure, has an important growth at a loading level of 1500N [2]. This effect can be explained by the occurrence of scuffing.

Several studies present aspects regarding the evolution of roughness parameters during friction and wear process. One of them was developed by Kubiak et colab. [3,4]. They demonstrate that the abrasive wear rapidly modifies the roughness parameters in contact and the initial condition of contact surfaces affects the contact lifetime. The same conclusion was demonstrated by Sedlacek et colab. [5].

Yuan has analyzed the evolution of roughness parameters under improper lubrication conditions [6]. He found that the evolution of the wear scar is dependent on lubricant quality and wear particle density and dimensions.

Dongare and Patil [7], describe a testing procedure for extreme pressure measurement of different lubricants using a four balls testing machine. Their test rig can be reproduced by adapting a drilling machine to the test particularities.

Starting from the above presented studies, the surface quality of the wear scar obtained on a four balls test was investigated considering that this study can be more accurate because it is developed in controlled conditions of speed, loading and lubrication. The present paper continues a previous
research by the authors and tries to understand the context of scuffing initiation due to mechanical parameters.

2. The experimental setup
A study regarding the evolution of contact surfaces quality during tests on a four balls machine using two different types of lubricants was conducted. Four identical balls, having 12.7 mm in diameter and roughness parameters, \( Ra \) 0.078 \( \mu \)m, \( Rz \) 0.739 \( \mu \)m and \( Rq \) 0.104 \( \mu \)m, were used. Three of the balls were blocked in a special cage forming a ball pot assembly and the fourth one was fixed in the ball chuck mounted on the testing machine spinning shaft. For testing, a bench drilling machine having 1600 rpm spinning velocity was adapted in order to ensure constant loading. To determine the global loading force, a force transducer was used. The loading force was generated by attaching weights to the modified drilling machine lever. The structure of the testing device used to ensure the relative position between balls and the relative motion is represented in figure 1.

![Figure 1. Loading device.](image)

3. Testing methodology and experimental results
Testing procedure respected the EN ISO 20623:2003 international standard. Two tests were made using XHP222 and U90Ca3 greases (NLGI 2) [8, 9]. The contact loading started from 100 N and was gradually increased by 100 N steps. The test procedure was stopped at 1700 N due to reaching the maximum loading capacity of the force transducer. For each loading step, testing takes 10 seconds. After each step, one of the balls from the ball pot assembly is cleaned and investigated using a laser profilometer. The surface quality and the dimensions of the contact wear scar were evaluated and represented graphically.
Two tests were made in similar conditions using the specified types of grease. The testing procedure started with complete filling of the assembly pot with grease and loading the contacts. The loading level was controlled using the force transducer. After loading the testing device to a desired level, the machine was started and the motion was maintained for 10 seconds. After each 10 seconds run, the lower cage (assembly pot) with the blocked balls was cleaned using a hydrocarbon-based solvent and the wear scar was analysed using a NanoFocus Microscan laser profilometer.

The wear scar dimensions and the roughness parameters were evaluated. The three dimensional topography of the wear scar was recorded for each loading level. Figure 2 graphically represents a typical example of 3D wear scar topography and a 2D profile.

![Figure 2. Typical results for XHP222 grease test.](image)

To validate the testing equipment and the testing procedure, own experimental values of the wear scar diameter were compared with those obtained by Dongare [7], who used a similar testing procedure and SAE 20 mineral oil for lubrication. Results obtained in the present investigations show a similar evolution with those obtained by Dongare. This similarity validates the testing equipment and the testing procedure.

The wear scar diameter was measured and the results were represented graphically as shown in figure 3. In figure 3.a, the wear scar evolution correlated with the loading level. The correlation between roughness parameter Ra and loading was represented in figure 3.b. From figure 3.a it can be observed that the wear scar diameter increases more rapidly at the beginning of the test due to contact wear initiation and has an important growth near the 500 N loading level. A similar evolution is observed in figure 3.b for the Ra roughness parameter.
Figure 3. (a) Correlation between wear scar dimension and load, (b) correlation between $Ra$ and load (test with U90Ca3 grease).

The evolution of the roughness parameters, $Ra$, $Rz$ and $Rq$ in four balls testing using different lubricants was investigated. The roughness parameters, $Ra$, $Rz$ and $Rq$ were measured in the middle cross sections, both perpendicular to contact sliding direction and along sliding direction. The evolutions of $Ra$, $Rz$, $Rq$ along sliding direction and perpendicular to the sliding direction were represented in figure 4. The experimental results reveal that the roughness parameters have different values on those two directions. The experimental values measured perpendicular to sliding direction are higher than those obtained along sliding direction. Roughness parameters have different values due to scratches generated by the relative motion between asperities only in one direction. Wear scar profile evaluation along the sliding direction and perpendicular to it showed significant differences in roughness parameters. This aspect can be also observed in figure 2.a. The asperities of the surfaces initiate adhesive wear along the sliding direction on both contact surfaces. The contact wear scar appears due to cumulative action of the scratches and adhesive wear. The roughness parameters are also influenced by the density and the depth of those scratches.

Figure 4. Evolution of $Ra$, $Rz$, $Rq$ along sliding direction and perpendicular to sliding direction (test with U90Ca3 grease).

Figure 5. Correlation between $Ra$, $Rz$, $Rq$ and load, measured perpendicular to the sliding direction.

Because the 2D roughness parameters along the sliding direction are different from those obtained perpendicularly to it [3], the surface roughness parameters were also investigated. For each loading level the magnitude of the arithmetical mean height, $Sa$, and the root mean square height, $Sq$, were analysed. Roughness gradient distribution for U90Ca3 grease tests corresponding to 200 N and 1400 N loading levels are presented in figure 6.
The evolution of the arithmetical mean height $S_a$ and root mean square height $S_q$, correlated with loading level were represented graphically in figure 7.

The experimental values reveal that near the 1500 N loading level, surface roughness parameters $S_a$ and $S_q$ have a significant growth. This evolution can be explained by the occurrence of flowed material extracted from the contact region and deposited in the output region of the contact area. The quantity of flowed material is dependent on contact loading level. Also, the contact pressure distribution can influence the roughness parameters.

4. Conclusions

The evolution of the wear scar roughness parameters obtained in four balls tests was investigated. Two types of grease were used in order to highlight the scuffing phenomenon occurrence. The testing methodology followed EN ISO 20623:2003 international standard. The contact loading was adjusted from 100 N to 1700 N, the maximum loading level admitted for the force transducer. The tests were made at 1600 rpm for 10 seconds periods, in 100 N steps. During the testing a wear scar area occurs. After each loading step, the wear scar area corresponding to one of the three locked balls was cleaned and investigated.

The dimensions of the scar area showed progressive increase correlated with relative motion time and with the applied load. The contact pressure varies with the global loading while the surfaces quality parameters stabilize.

The experimental results reveal that the values for arithmetic mean deviation of the assessed profile, $Ra$, and mean roughness depth of the profile, $Rz$, stabilized around 1.5 µm, corresponding to
1500 N loading level. The root mean square deviation of the assessed profile, $Rq$, stabilizes at approximately 2 µm for the same abovementioned loading level.

The evolutions of the $Ra$, $Rz$, $Rq$, parameters along sliding direction and perpendicular to it were also investigated. The experimental results reveal that the roughness parameters obtained for profiles perpendicular to sliding direction have higher values than those obtained along sliding direction. A similar evolution was highlighted by Kubiak [3]. Due to this aspect, the surface roughness parameters were also investigated. The experimental values for the arithmetical mean height, $Sa$, and root mean square height, $Sq$, were obtained for each loading step in both tests. By analyzing the evolution of the surface roughness parameters, the arithmetical mean height, $Sa$, and root mean square height, $Sq$, it can be observed that both parameters have a significant growth near the 1500N loading level. This growth may be due to high contact pressure and temperature. As the wear scar area increases the displaced (flowed) material is deposited in the contact output region. In this region the roughness parameters have high values.

The dynamic evolution of the wear scar roughness parameters shows that the scuffing phenomenon appears when the total number of micro contacts between surfaces asperities exceeds a certain value or the density of the surfaces asperities density exceeds a critical level. After a certain loading level, the density and the magnitude of asperities will be relatively constant and only the contact dimension will be in direct correlation with load and scuffing occurrence.

5. References
[1] EN ISO 20623:2003 Petroleum and related products-Determination of the extreme pressure and anti-wear properties of fluids - Four ball method (European conditions)
[2] I C Românu, I Muscă, N Couțun and A Juravle 2016 A simple solution for evaluation of lubricants anti-wear properties IOP Conference Series: Materials Science and Engineering 147 doi:10.1088/1757-899X/147/1/012025
[3] K J Kubiak, M Bigerelle, T G Mathia, A Dubois and L Dubar 2014 Dynamic evolution of interface roughness during friction and wear processes Scanning 36 pp30-38 doi:10.1002/sca.21082
[4] K J Kubiak, T W Liskiewicz and T G Mathia 2011. Surface morphology in engineering applications: influence of roughness on sliding and wear in dry fretting Tribology International 44:1427–1432.
[5] M Sedlacek, B Podgornik and J Vizintin 2008 Influence of surface preparation on roughness parameters, friction and wear Wear 266 pp.482-487
[6] C Q Yuan, Z. Peng, X P Yan and X C Zhou 2008 Surface roughness evolutions in sliding wear process Wear 265 pp.341-348
[7] A D Dongare and G J Vikhe Patil 2012 The standard test method for measurement of extreme pressure properties of various lubricants oils by using four ball extreme pressure oil testing machine International journal of engineering science invention research & development 4
[8] http://www.smeertechniek.com/img/downloads/files/mobilgrease_xhp_222_pds.pdf
[9] http://www.lubrifianti.com/documente-up/fisa-tehnica_13861.pdf
[10] E S Gadelmawlaa, M M Kourab, T M A Maksoudc, I M Elewaa and H H Soliman 2002 Roughness parameters Journal of Materials Processing Technology 123 doi.org/10.1016/S0924-0136(02)00060-2

Acknowledgments
This paper has been financially supported within the project entitled „DECIDE - Development through entrepreneurial education and innovative doctoral and postdoctoral research, project code POCU / 380/6/13/125031, project co-financed from the European Social Fund through the 2014 – 2020 Operational Program Human Capital”