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HARDENING MONITORING AND CONTACT STRESS ANALYSIS OF TEST SAMPLES

Summary. The presented paper deals with the solution of rolling contact problem. A virtual model was created in Abaqus FEA software. The boundary conditions and contact forces were subsequently added. The results obtained after the simulation were compared with data obtained by experimental measurements, which were performed on the test stand ELSPO used in theoretical and technological center for plastometer construction materials for experimental analyzes and tests in terms of rolling contact of solids. The FEM simulation and experiment observed the size of the contact pressure, plastic deformation and the width of the track, which was the site of contact.
Keywords: point, rolling contact, finite element method, experiment.

MONITOROWANIE UTWARDZANIA PRÓBEK BADAWCZYCH ORAZ ANALIZA NAPRĘŻEŃ STYKOWYCH

Streszczenie. Przedstawiony artykuł jest poświęcony rozwiązaniu problemu styku tocznego. W MES programie Abaqus został skonstruowany model wirtualny. Następnie dla modelu zastosowano warunki graniczne i siłę styczną. Wyniki uzyskane na podstawie symulacji zostały porównane z analizą doświadczalną problemu, którą przeprowadzono na maszynie doświadczalnej ELSPO, stosowanej w Centrum Plastometrii Teoretycznej i Technologicznej Materiałów Konstrukcyjnych do analiz doświadczalnych oraz badań w warunkach styku tocznego ciał sztywnych. W trakcie symulacji MES oraz doświadczenia obserwowano wielkość naprężeń von Misesa, ciśnienia stykowego, deformacji plastycznej oraz szerokości śladu, jaki powstawał w miejscu styku.
Słowa kluczowe: styk punktowy, styk toczny, metoda elementów skończonych.

1. INTRODUCTION

The aim of the numerical solution of contact problems is to deal with the is to capture the movement of bodies, apply constraint conditions, prevent penetration and apply appropriate boundary conditions to simulate the behavior of friction and heat transfer.

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The finite element method (FEM) can examine the values and distributions of surface and subsurface stresses with high accuracy. The progressive power of computers leads to more sophisticated and technically sophisticated models in engineering analysis [1]. Mathematical description of consequences of contact, which are leading to a nonlinear problem of boundary conditions were developed advanced simulation programs for contact problems using finite element method software such as Abaqus, Ansys, MSC Patran and Adina. In the last years they contain different discretization methods for solving small and large deformations. Adaptive methods based on controlling the error in the finite element analysis and mesh adaptation are most focused on the reliability of numerical computation of contact problems.

2. NUMERICAL SOLUTION OF ROLLING CONTACT

Rolling contact, in which plastic deformations are originated, can be simulated with the help of FEM solve with using the contact elements or method of contact pressure. The first option to solve the rolling in one direction is complicated because it is necessary to indicate the roll of the bodies to its original position and the difficulty arises with the convergence of the calculation with higher coefficients of friction. The second option is shifting the distribution of surface contact pressure and friction stress. Problems with convergence here drop out, but it is necessary to know the size and shape of the contact area [4, 5, 6]. For this purpose it is possible to use the results of numerical calculation using contact elements, or experimental data. Solving such problems with the displacement surface pressure method is very effective. This method can be applied in commercial FEM programs defining the boundary conditions using a mathematical function [2].

2.1. Determination of the boundary conditions at the line contact

In case of line contact, planar deformation state can be considered. If there are small plastic deformations, normal surface pressure is used to enter the values of the relationship based on the Hertz theory of elasticity:

$$p(x) = p_0 \sqrt{1 - \left(\frac{x}{a}\right)^2} \tag{1}$$

where:
a - half-axis of the ellipse;
p_0 - the maximum value of the contact pressure;
x - selected radius.
P_0 must correspond to the normal force F (Fig. 1), so that:

$$F = \int_{-a}^{a} p(x)dx = \frac{\pi}{2} p_0.a \tag{2}$$

In the case of negligible slippage is possible to consider Coulomb friction applied to shear stresses on the surface proportional to the normal pressure according to the equation:

$$\tau(x) = f.p \tag{3}$$

where:
f - friction coefficient.

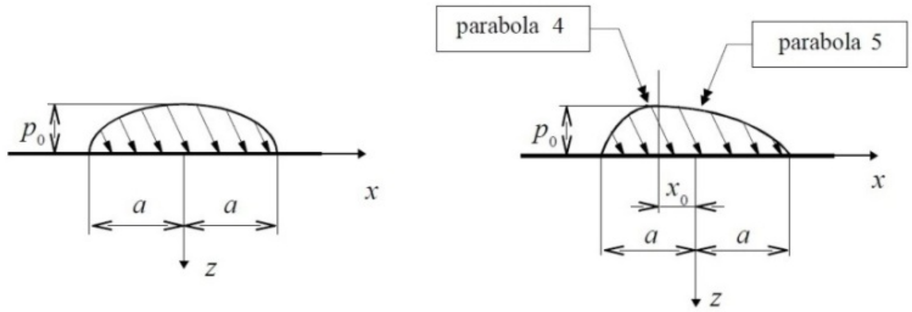


Fig. 1. Stress waveform according to Hertz (left) and the proposed approximation function (right)
Rys. 1. Przebieg naprężenia według Hertza (po lewej) oraz zaproponowana funkcja aproksymująca (po prawej)

Results from the numerical analysis have shown, that for loads above of the permanent plastic adaptation it is suitable to approximate the course of the contact pressure propose with a different function than with that in equation (1), namely one that is easy to apply in the displacement surface pressure method. Very useful is the use of two parabolas, then this approximation can be described by the equation:

$$p(x) = p_0\left(1-\left|\frac{x-x_0}{a-x_0}\right|^{m_1}\right),\ pre - a \le x \le -x_0 \tag{4}$$

$$p(x) = p_0\left(1-\left|\frac{x-x_0}{-a-x_0}\right|^{m_2}\right),\ pre - x_0 < x \le a \tag{5}$$

where:
x_0, m_1, m_2 - appropriately chosen parameters.

Shear stress can be entered in the case of small slip, equation (3). By its application it is necessary to consider the direction of an induced friction T. This direction depends on whether the rolling part of the drive drives or is driven Fig. 2. The drive elements frictional forces act against the direction of movement of the driven element and the direction of motion (true law of action and reaction). Arrows in Fig. 2 indicate the direction of rotation of the components. When applying the scrolling surface pressure method, the distribution of surface tension moves against the direction of rotation[4, 7]. The ratio between T and the normal force F indicates the friction coefficient f [2].

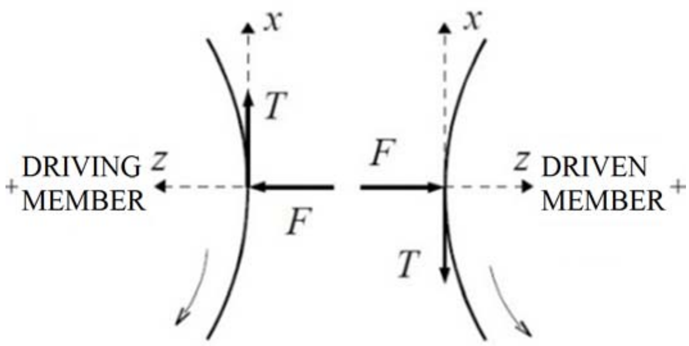


Fig. 2. Direction of action of frictional forces
Rys. 2. Kierunek działania sił tarcia

2.2. Determination of the boundary conditions at the point contact

Simulation of point contact by FEM is more difficult than line contact, because of the changing size of the contact area with the load and with the number of cycles. The bigger the load, the more the pressure distribution changes the size of the contact surface. The most commonly used function is again taken from the Hertz elasticity theory, where the normal pressure is defined by :

$$p(x,y) = p_0 \sqrt{1-\left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2} \tag{6}$$

where:
a, b - driveshafts contact ellipse;
p_0 - the maximum value of the normal pressure;
x - selected radius.
P_0 must correspond to the normal force F (Fig. 3), so that:

$$F = \int_S p(x,y)dS = \frac{2}{3} p_0.\pi.a.b \tag{7}$$

To enter the shear stress is again used equation (3). The Hertz during normal pressure as possible to actual progress at the beginning of the roll is [3].

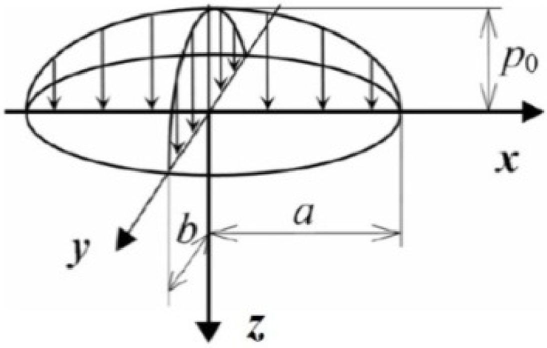


Fig. 3. Progress under normal voltage Hertz at points of contact
Rys. 3. Przebieg naprężenia normalnego według Hertza podczas styku punktowego

3. EXPERIMENTAL AND NUMERICAL ANALYSIS OF TEST SAMPLE

The experimental analysis was performed on the experimental system which allows analysis of rolling contact of metallic bodies, which is located in the Centre of theoretical and technological plastometry at Metal Engineering Faculty of the University of Žilina. It can precisely assess the issue of contact stresses of steel discs with point and rectilinear contact with the surface of the test samples of steel 11 500 (Young's modulus of elasticity E = 210 GPa) and then compare the experimental results with FEM simulation.

The experiment uses the test discs for point contact Fig. 4. Material test discs, made from bearing steel 14 201 (Young's modulus of elasticity E = 210 GPa, hardness 63 - 64 HRC after heat treatment).

Fig. 4. Test discs for point contact
Rys. 4. Tarcze próbne dla styku punktowego

The experiment was carried out on the testing stand ELSPO Fig. 5, which is used in the Centre of theoretical and technological plastometry construction materials for experimental analyzes and tests under conditions of rolling contact of solids.

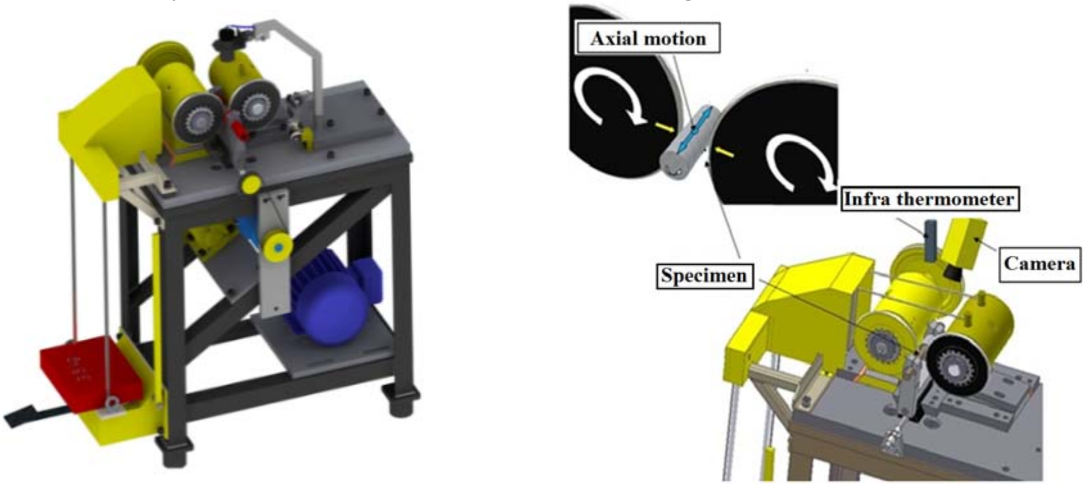


Fig. 5. Testing stand
Rys. 5. Maszyna doświadczalna

Fig. 6 shows the test sample is clamped in the holder.

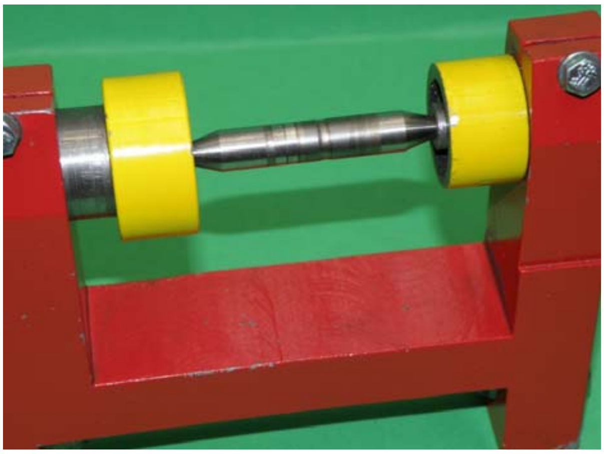


Fig. 6. Clamped test sample
Rys. 6. Zastosowana badana próbka

Before starting the experiment conditions under which the experiment was conducted were set. Conditions were established peripheral velocity, contact force and the number of cycles. The values of these variables are shown in table 1.

Table 1

The conditions for the experiment

	Compressive force [N]	**Tangential velocity [$m.s^{-1}$]**	**Number of turns**
Point contact	157	2	25 000

Table 2 shows the measured value of the trace width at the end of the experiment.

Table 2

Readings trace width

	Traces width [mm]
Point contact	1,673

Fig. 7 shows the trace width, which was measured using the Control web software after the experiment.

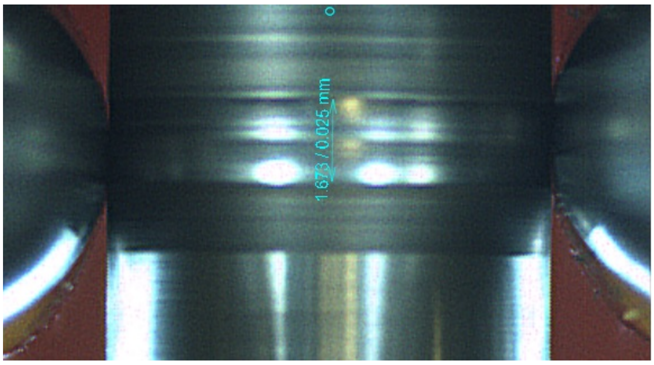


Fig. 7. Measured trace width
Rys. 7. Zmierzona szerokość śladu

4. FEM SIMULATION EXPERIMENTS

The simulation was performed using FEA software Abaqus. The aim of FEM simulation was to evaluate the surface of the sample made from 11 500 material, in contact with the test discs after 25 000 rotations. The next aim was to evaluate the value of the equivalent (von Misses) stress, contact pressure and the plastic deformation at the specified value of the contact force.

The 3D model of the sample and test discs of the experiment was created in Abaqus working environment.

Experimental measurements have shown that the steel 11 500 has isotropic properties in all directions, so isotropic material model was chosen. For test discs rigid body material properties were selected.

All boundary conditions were applied to the reference points. The test sample were constrained on both ends, all three translational degrees of freedom along the axes X, Y, Z and two rotational degrees of freedom in the direction of axes X and Y, that the model does not move in space. Rotation in the direction of the Z axis is unconstrained.

The test discs were taken on both sides of the two translational degrees of freedom and in the Y direction, Z and two rotational degrees of freedom in the direction of the X - axis and Y. The unconstrained translational degree of freedom in the direction of X - axis and rotation in the direction of the Z axis is used to move the test discs to the sample and spin discs.

Because it was necessary to analyze the surface of the sample by rolling contact, the surface of the sample was meshed by smaller elements. The test sample had 872 910 elements, 890 071 nodes and test disc 39 202 elements, 41 646 nodes.

Results for simulation are compiled in table 3, which shows the resulting values of equivalent (von Misses) stress, contact pressure and plastic deformation of the samples surface in contact between the sample and test discs and after 25 000 rotations, which describes the state of completion of the experiment.

Table 3

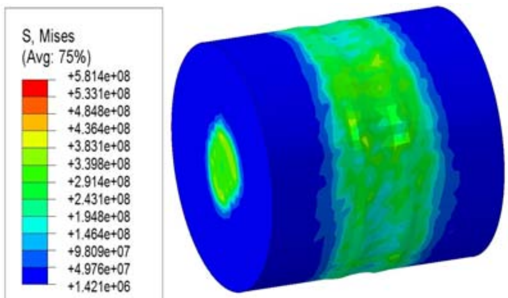
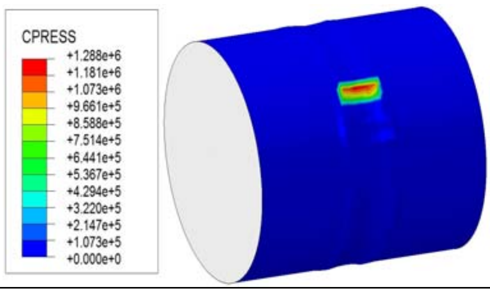
Results of the analysis point contact

	Point contact
Compressive force [N]	157
Number of turns	25 000
Equivalent stress [Pa]	$5{,}814.10^{8}$
Contact pressure [Pa]	$1{,}288.10^{6}$
Plastic strains	$3{,}940.\ 10^{-2}$

Table 4 shows the images of finite element analysis for point contact.

Table 4

Evaluation of FEM simulation

<table>
<tr><td colspan="3">Point contact</td></tr>
<tr><td>Compressive force [N]</td><td>157</td><td rowspan="4">
</td></tr>
<tr><td>Number of turns</td><td>25 000</td></tr>
<tr><td>Traces width [mm]</td><td>1,673</td></tr>
<tr><td>Equivalent stress [Pa]</td><td>$5{,}814.10^{8}$</td></tr>
<tr><td>Contact pressure [Pa]</td><td>$1{,}288.10^{6}$</td><td>
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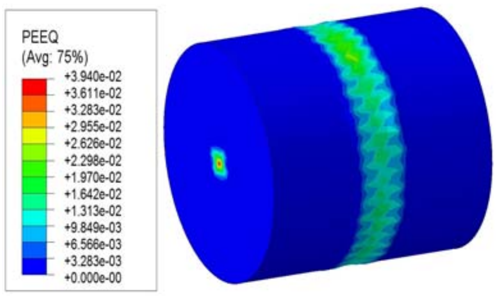
<tr><td>Plastic strains</td><td>$3{,}940.\ 10^{-2}$</td><td>
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5. CONCLUSION

Values observed equivalent (von Misses) stress, deformation and their components arising at the site of contact test discs and samples can be further used in examining the initiation and propagation of fatigue cracks on the surface or below the surface of the material and making the fatigue life of the curves for 11 500 steel. Other and further investigations and experiments can establish fatigue curves for other metallic materials, like Mg, Al, Ti etc. Also the paper presents the possibility of simulating such problem via FEM, which enables to obtain results without making expensive experiments.

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