23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

NUMERICAL METHOD FOR DETERMINING THE MAIN FORCE OF BURNISHING ROLLING OF ROUGH CYLINDRICAL SURFACE WITH REGULAR PERIODICAL OUTLINES ASPERITIES

S. Patyk[*], R. Patyk[**], L. Kukiełka[***], P. Kałduński[****], J. Chojnacki[*****]

Abstract: *The article presents a numerical method for determining the main force of burnishing rolling of rough surface with periodic regular outline asperities. This is a basic problem, the solution of which is integral to the design of a technological process using surface forming. As part of the work to solve the problem the physical, mathematical and computer modelling methods were used. An algorithm for specifying the main force burnishing has been developed, assuming that the burnishing of the surface is determined with regular and periodic roughness profile. The solution of developed equations of the object motion was performed using the finite element method.*

Keywords: Burnishing rolling, Surface layer, Technological quality, DEM, Numerical analysis.

1. Introduction

The main problem in the design process of burnishing is the selection of the optimal values of technological parameters (Bohdal et al., 2016). The most important of these parameters is the main burnishing force F_3, which is a normal component of the resultant burnishing force F (Kulakowska et al., 2008, Kulakowska et al., 2014). Improper selection of this parameter causes unintended dimensional changes and the formation of the surface layer properties which do not comply with requirements. In extreme cases, it would cause damage to the surface layer of the object. Hitherto, the use of burnishing as very accurate finishing operation was associated with carrying out experimental research for each process. On the basis of these studies the technological parameters were determined (Kulakowska et al., 2016). Therefore, formulas reported in the literature for the burnishing forces calculation are an empirical formulas. A multitude of solutions proposed by different authors leads to compare the results of the forces calculated by various empirical formulas (Kukielka et al., 2008, Kukielka et al., 2010). The example of burnishing of spigot shaft surface was analysed. The most famous solutions for calculating the main burnishing force F_3 are formulas, given by Hegenscheidt, Kudryavtsev, Chejfic, Kudryavtsev - Chejfic, Drozd, Ivanov, which are citated i.a. in the works (Kukielka, 1994, Przybylski, 1987, Patyk, 2010). The values of the forces F_3, necessary to strengthen the surface layer to a depth of $\delta = 3$ [mm], which are calculated on the basis of these correlations, for the case of the burnishing shaft having a diameter of part d = 500 [mm], the hardness of the materials HB = 250, yield stress Re = 400 [MPa], tensile strength Rm = 600 ÷ 710 [MPa], with burnishing element as a form of two-toroidal disk with diameter D = 100 [mm] are respectively: F_3= 417.2 [kN]; 7.2 [kN]; 9.5 [kN]; 93.8 [kN]; 53 [kN] and 430 [kN]. When independed technological parameters of burnishing process are: velocity (v) feed rate (f) and the burnishing depth (g), the output parameter is the main normal force (F_3), which also depends on the

[*] PhD.:Faculty of Mechanical Engineering, Koszalin University of Technology, Raclawicka Street 15-17; 75-620 Koszalin; PL, sylwia.patyk@interia.pl

[**] PhD.:Faculty of Mechanical Engineering, Koszalin University of Technology, Raclawicka Street 15-17; 75-620 Koszalin; PL, radoslaw.patyk@tu.koszalin.pl,

[***] Prof.:Faculty of Mechanical Engineering, Koszalin University of Technology, Raclawicka Street 15-17; 75-620 Koszalin; PL, leon.kukielka@tu.koszalin.pl, jerzy.chojnacki@tu.koszalin.pl

[*****] PhD.:Faculty of Mechanical Engineering, Koszalin University of Technology, Raclawicka Street 15-17; 75-620 Koszalin; PL, kaldunski.pawel@tu.koszalin.pl,

[*****] Prof.:Faculty of Mechanical Engineering, Koszalin University of Technology, Raclawicka Street 15-17; 75-620 Koszalin; PL, jerzy.chojnacki@tu.koszalin.pl,

previous operation before the treatment and on the conditions of the process. In case of burnishing with elastic-loaded force, operation does not depend on the size of the final machining allowance for burnishing, but depends on the elastic-loaded element settings such as springs tools, pneumatic and hydraulic. Then the resultant force F_3 assumes a constant value during processing. Technological parameters of such process are: the main burnishing force (F_3), velocity (v), feed rate (f). The output parameter is the value of depth (g). Inappropriate selection of process parameters, primarily burnishing force, can cause damage the surface layer of the workpiece by its peeling, surface cracks, etc. This issue appears because at the absence of guidance it is easy to exceed the force required for a particular type of material and material properties, and treatment conditions prior to burnishing (Patyk, 2015). Influence of main burnishing force on deformation of surface layer of burnishing product is shown in Fig. 1.

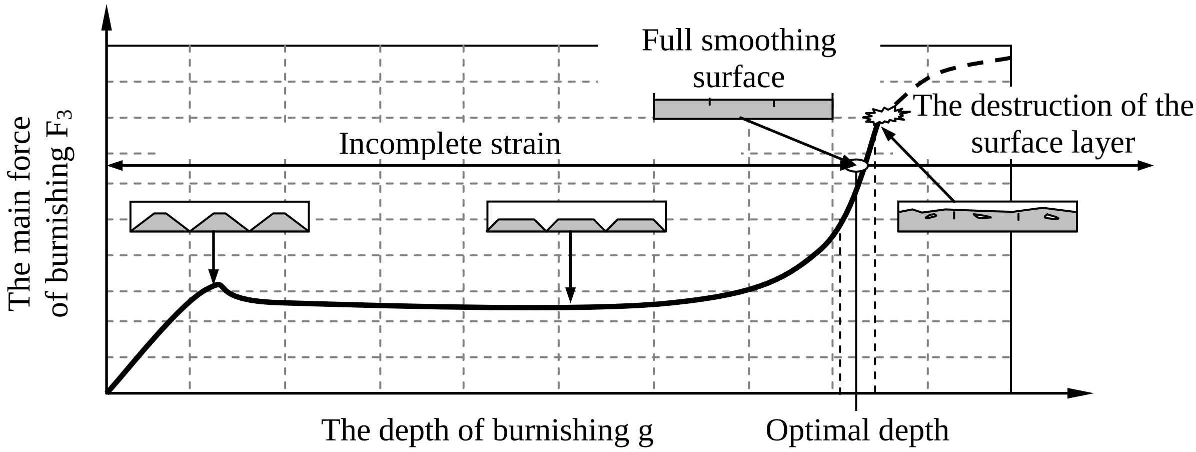

Fig. 1: The impact of the main force of burnishing F_3 on the properties of the surface layer of the burnish product.

The aim of the research was developing an application for the determination of the main force of burnishing. The authors of this publication, in the previous studies and analyzes, have shown that modelling with using finite element method is an effective method of obtaining the large convergence to results from experimental research, therefore, to determine the forces in the rough rolling burnishing with rollers this method was used (Kukielka et al., 2016, Patyk et al., 2008, Patyk, 2010).

2. Numerical model of burnishing rolling of cylindrical rough surface

The authorial software BURNISHING FORCE has been elaborated in the ANSYS APDL language (Patyk et al., 2014). It has been developed as a three-dimensional model of the process. The object and a tool was discretized as elements of the type of solid.

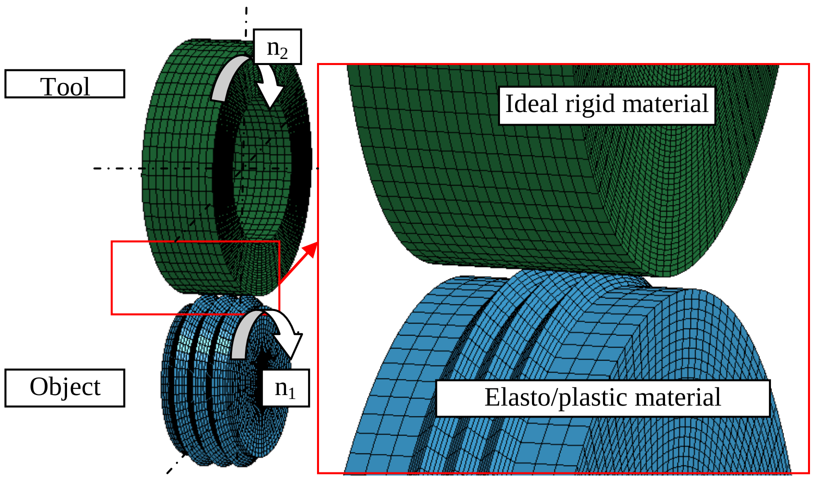

Fig. 2: Discrete model of the burnishing rolling process of shafts with regular periodical outlines asperities.

The tool was discretized by 10 000 finite elements, but the object is discretized by 550 000 finite elements. The tool was pressed into a rotating object to the second limit depth (Fig. 2). A discrete system of equations of motion are solved using the DEM (dynamic explicit method of integration - central differences) method (Patyk et al., 2009, Patyk et al., 2014, Patyk et al., 2016). Examples of the simulation results of the burnishing rolling process of shafts with roughness surface is shown in Fig. 3 (state of plastic deformation for different degrees of advancement of the process). The developed numerical model was used to determine changes of the main burnishing force (maximum value) from: yield stress of the material Re, module of material hardening E_T, the apex angle of the regular triangular asperity 2θ, spacing of individual asperities from each other f. Analyses were performed for typical ranges of material parameters and technological processes (Figs. 4 and 5).

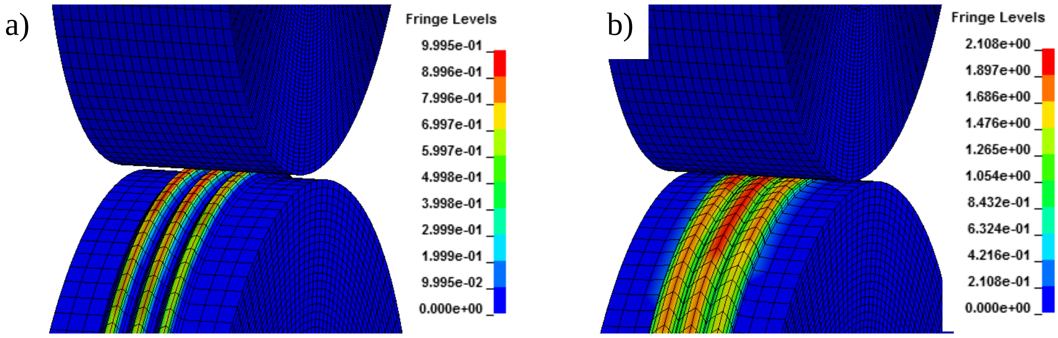

Fig. 3: State of reduced plastic strain for the case of a rolling burnishing shafts rough with apex angles of inequalities 2θ = 90 °, f = 1.5 mm, for the material S235JR, for: a) 30 % and b) 60 % of advancement of the process.

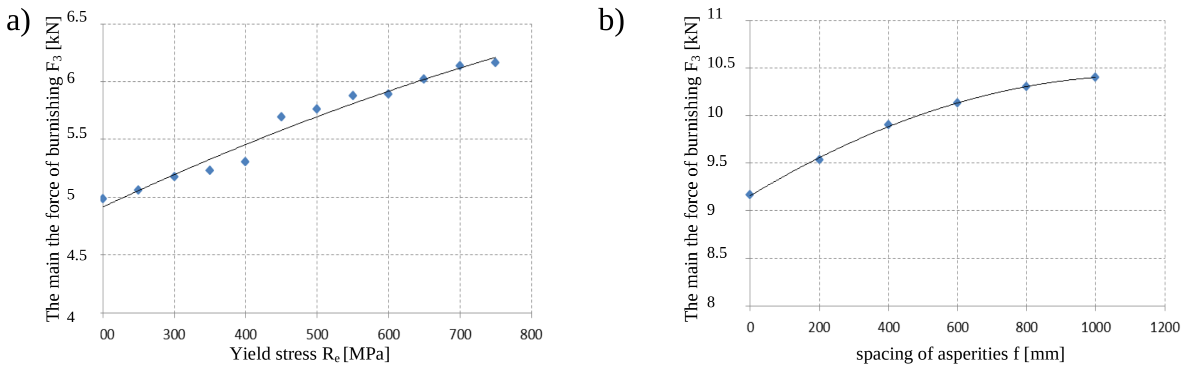

Fig. 4: Graph of the main burnishing force depending on the: a) yield stress R_e for: apex angle 2θ = 90 °, feed f = 1 mm, hardening modulus E_T = 500 MPa and static friction coefficient μ = 0.2, b) hardening modulus E_T for: apex angle 2θ = 90 °, feed f = 1.5 mm, yield stress R_e = 420 MPa and static friction coefficient μ = 0.2.

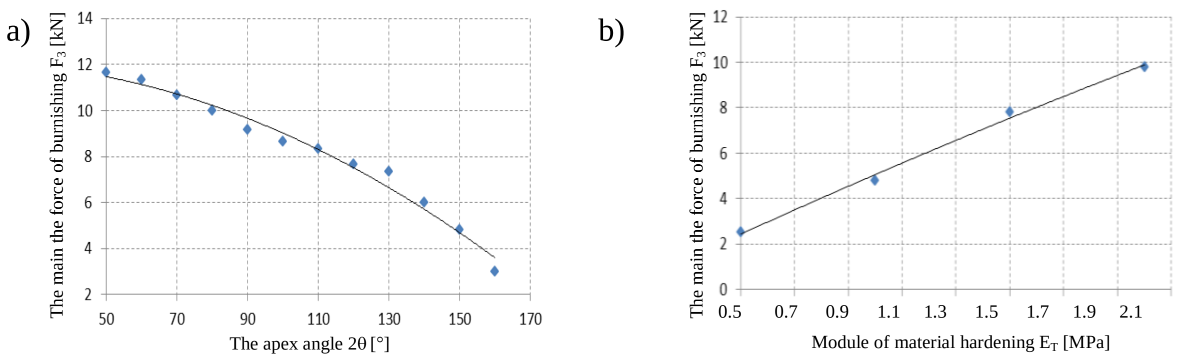

Fig. 5: Graph of the main burnishing force depending on the: a) apex angle for: feed f = 1.5 mm, yield stress R_e = 420 MPa and static friction coefficient μ = 0.2 and hardening modulus E_T = 500 MPa and b) asperities of the distance from each: for yield stress R_e = 420 MPa, static friction coefficient μ = 0.2, hardening modulus E_T = 500 MPa, apex angle 2θ = 120 °.

3. Conclusions

The developed application BURNISHING FORCE with using the finite element method, in order to determine the main force burnishing, has proven to be the most effective method from among previously used (analytical methods and experimental studies) because: allows to create adequate numerical models of the process of burnishing rolling of cylindrical rough surface (cheaper and faster) and obtained results of numerical simulations are consistent with experimental results. There is possible quickly modification of the model and adaptation it to the other cases. This will significantly shorten the time and reduces costs for selection of optimal technological parameters of the process (particularly the main burnishing force).

References

Bohdal, L., Kulakowska, A., Patyk, R. and Kulakowski M. (2016) Numerical investigations of the effect of process parameters on residual stresses, strains and quality of final product in blanking using SPH method, Materials Science Forum, Vol. 862, pp. 238-245.

Kułakowska, A. and Kukiełka, L. (2008) Problems of surface preparation in turning process in aspect of technological quality of burnished product, Pomiary Automatyka Kontrola Vol. 54, No. 7, pp. 421-424, (in Polish).

Kulakowska, A., Patyk, R. and Bohdal, L. (2014) Application of burnishing process in creating environmental product, Annual Set The Environment Protection, 16, pp. 323-335.

Kulakowska, A., Kulakowski, M., Bohdal, L. and Patyk, R. (2016) Aspects of burnishing rolling process of the surface prepared in different previous treatments, Materials Science Forum, Vol. 862, pp. 78-85.

Kukiełka, L., Kułakowska, A. and Patyk, R. (2008) Problematics of parts technological quality forming in burnishing rolling process, Pomiary Automatyka Kontrola, R. 54, No 4, pp. 196-199, (in Polish).

Kukielka, L., Kulakowska, A. and Patyk, R. (2010) Numerical analysis of embossing process of regular inequalities with triangular outline on cylindrical semi product, Journal of Systemics, Cybernetics and Informatics. Vol. 8, No. 3, pp. 36-41.

Kukiełka, L. (1994) Theoretical and experimental base surface burnishing rolling contact with electrical heating, Monography no 47, Koszalin (in Polish).

Kukielka, L., Szczesniak, M., Patyk, R., Kułakowska, A., Kukielka, K., Patyk, S., Gotowala, K. and Kozak, D. (2016) Analysis of the States of Deformation and Stress in the Surface Layer of the Product after the Burnishing Cold Rolling Operation, Materials Science Forum, Vol. 862, pp. 278-287.

Patyk, R., Patyk, S. and Kukiełka L. (2015) Determination of the principal burnishing force roller rouhnes surface with regular periodical outlines asperities using numerical methods, Mechanik 2015, 3, pp. 270-280 (in Polish).

Patyk, R., Patyk, S. and Kukiełka L. (2009) The numerical determination of contact zone tool and work-pieces in burnishing rolling process, Computer Methods in Materials Science 2009, Vol. 9, No. 1, pp. 61-65.

Patyk, R., Kukielka, L., Kukielka, K., Kułakowska, A., Malag, L. and Bohdal, Ł. (2014) Numerical Study of the Influence of Surface Regular Asperities Prepared in Previous Treatment by Embossing Process on the Object Surface Layer State after Burnishing, Applied Mechanics and Materials, Vol. 474, pp. 448-453.

Patyk, R., Kułakowska, A. and Bohdal, Ł. (2014) Environmental, economic and exploitation aspects of the use of burnishing rolling treatments, Annual Set The Environment Protection 2014, Vol. 16 part. 1, pp. 351-362.

Patyk, R. (2010) Theoretical and experimental basis of regular asperities about triangular outline embossing technology. Steel Research International, vol.81/9, pp. 190-193.

Patyk, R. and Kukielka, L. (2008) Optimization of geometrical parameters of regular triangular asperities of surface put to smooth burnishing. Steel Research International, 2, pp. 642-647.

Patyk, R., Bohdal, Ł. and Kułakowska, A. (2016) Study the possibility of controlling the magnitude and distribution of residual stress in the surface layer of the product after the process double duplex burnishing, Materials Science Forum, Vol. 862, pp. 262-269.

Patyk, S. and Patyk, R. (2010) The methodologies of force parameters determination in burnishing rolling process of rough surface, Logistyka 2010, 2, pp. 2087-2096 (in Polish).

Przybylski, W. (1987) Processing technology burnishing, WNT, Warsaw (in Polish).