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*surface preparation,
burnishing rolling, numerical analysis,
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NUMERICAL ANALYSIS OF THE INFLUENCE OF SURFACE ASPERITY VERTICAL ANGLES AFTER TURNING ON THE STATE OF STRESS AND STRAINS AFTER PART'S BURNISHING ROLLING

In the paper numerical analysis of the influence of surface asperity vertical angles after turning on the state of stress and strains after part's burnishing rolling are presented. The analysis covers asperities with vertical angles in range 60÷150 degrees. The results of numerical analysis from ANSYS LS-Dyna program are presented. Graphs of the dependence of the stress intensity and total mechanical strain after burnishing rolling from the vertical angles of asperity after turning are presented.

ANALIZA NUMERYCZNA WPŁYWU KĄTA WIERZCHOŁKOWEGO NIERÓWNOŚCI POWIERZCHNI PO TOCZENIU NA STAN NAPRĘŻEŃ I ODKSZTAŁCEŃ CZĘŚCI PO NAGNIATANIU TOCZNYM

W pracy przedstawiono analizę numeryczną wpływu kąta wierzchołkowego nierówności powierzchni po toczeniu na stan naprężeń i odkształceń po nagniataniu tocznym części. Analizą objęto nierówności o kącie wierzchołkowym w zakresie 60÷150 stopni. Przedstawiono wyniki analiz numerycznych wykonanych w programie ANSYS/LS-Dyna. Sporządzono wykresy zależności maksymalnych intensywności naprężeń, maksymalnych intensywności odkształceń po nagniataniu od kąta wierzchołkowego nierówności po toczeniu.

1. INTRODUCTION

More often using of plastic treatment in car's parts production processes allows receiving products about longer exploitation time. One of the plastic methods of finishing metal treatment is burnishing rolling. This treatment allows receiving products with low roughness as well as constituting for the benefit of pressed stress [3]. The technological quality of the part after burnishing rolling considerably depends on the product's technological quality after previous treatment.

Essentially influence on the product's quality after burnishing rolling have: geometrical structure of the surface under burnishing rolling, relation of the burnishing feed and feed during previous treatment, outline of the burnishing element and the state of the slip in contact zone, burnishing depth as well as placing of burnishing element in the regard of

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treated product asperity. So far there are no unequivocal directions about surface preparation under burnishing rolling.

From the team researches [1, 2, 4, 5] arise, that there is a correlation between the state of the product after previous treatment and technological quality. The best results one receives when the geometrical structure of the surface after previous treatment is regular, determined, symmetrical and periodical.

2. VERTICAL ANGLE OF THE TRIANGULAR ASPERITY

Authors [1, 4, 5], with the assumption that the asperity of the surface after previous treatment is regular, symmetrical, and triangular and that it is symmetrical deformity, single out three qualitatively different cases of the material flowing in the product's Surface Layer (SL) during burnishing rolling process depending only on the vertical angle θ oft he asperity:

1) for the vertical angles $\theta \leq 80°$ a strain of the material occurs only in the area of asperities. The valleys of asperities do not rise. The core of the material remains unstrained. With a total strain, deformed asperities are visible and are separated from one to another with gaps (discontinuity planes) with the depth $0.5R_z$. The levelling of the surface occurs as a result of the flow of the material of asperities to sides.
2) for the vertical angle $80° < \theta < 145°$ there occurs an increase of the zone of plastic strains, which cover the core of the material, as well. The asperity valleys rise, while with a total strain, in the contact zone of neighbouring fashes, gaps are visible, yet with a smaller depth than previously
3) for the vertical angle $\theta \geq 145°$ the levelling of the surface occurs as a result of a strain of asperities and the core of the material, and not at the cost of the material fashes, in the direction of the sides of asperities. The value of the lowering of the vertex of asperities equals the value by which its valley rises. In the surface layer, there are no planes of the material's discontinuity

So it is important to receive after previous treatment not only regular outline, but also adequate vertical angle θ of the shaping asperities. The values of the vertical angle θ of the asperity and the feed during previous treatment should be taken every time for the part and it's inappropriate.

3. NUMERICAL ANALYSIS

The process of burnishing rolling was considered as a geometrical and physical boundary and initial value problem, with unknown boundary conditions in the contact area. An updated Lagrange's description was used for the characteristic of non-linear phenomena on a typical incremental step time. The increments of strains and stresses were described with an increment of a non-linear Green-Lagrange's strain tensor and an increment of the second symmetric Pioli-Kirchhoff's stress tensor respectively. For the purpose of a variational formulation of the incremental equation of the object's movement for the case of stress rolling burnishing, a variational functional was introduced, in which there occurs only one independent field, namely the field of an increment of displacements. Moreover, it was accepted that compatibility equations are satisfied and the initial and boundary conditions are fulfilled. Such assumptions lead to the so-called compatible model for the problems of non-linear dynamics, which is expressed in the increments of displacements.

The mathematical incremental model of the process for typical step time t-t+Δt, including: material model, model of yield stress, contact model, variational formulation of incremental equation of motion, discrete equation of motion, with initial and boudary conditions, DEM solution and DEM algorithm was presented with all details in work [6, 7].

4. COMPUTER SIMULATION

4.1 Applications

Computer simulations in Ansys LS-Dyna version 11.0 were prepared. In each case of numerical analysis applications in APDL language (Ansys Parametric Design Language) in aim to parameterization the geometrical size and material properties were elaborated. It allows making easy modifications and changes of model parameters. In each application one can change value of decelerated parameters: height of asperities (and what is connected vertical angle of asperity) as well as its distance, radius of peak and volleys round, height of core, material model parameters, friction coefficient and other [8]. The application for asperities with vertical angles *θ =(60°, 75°, 90°, 105°, 120°, 135° and 150°)* were prepared.

4.2 Geometry

The analysis included asperities about vertical angles in range 60÷150 [°]. In all cases, the same height of core H=7,65 [mm], was established. There was also constant value of asperities distance s=1,35 [mm] (fig. 1). The height of asperities was changed. The height of asperities h depended on the vertical angles of asperities. The values of asperities height, number of finite elements and nodes for application with different values of vertical angle are presented in table 1. The burnishing rolling process was conducted on the depth a_n which equals a half of asperities height a_n=1/2h.

Tab. 1.Vertical angles, height of asperities, number of finite elements and nodes

Vertical angle θ [°]	**60°**	**75°**	**90°**	**105°**	**120°**	**135°**	**150°**
Height h[mm]	2,34	1,76	1,35	1,04	0,78	0,56	0,36
Number of elements	9717	9725	7716	7598	7196	6734	6312
Number of nodes	6623	6552	4337	4278	4077	3846	3635

The exemplary analyses were conducted for the cases with plane strain and spacious state of stress. The numerical analyses of burnishing rolling process were conducted in two steps. The first step concerns the interaction of the tool, while the second one concerns the shift of the punch.

4.3 Material model

In the analyses the burnishing tool is treated as ideally rigid, and the object as the elasto/plastic with nonlinear hardening [3]. Classical bilinear isotropic hardening model (strain rate independent) uses two slopes (elastic and plastic) to represent the stress-strain behaviour of a material. The dates input into this model: elastic modulus ($E=2,1\cdot 10^{11}$), Poisson’s ratio (ν=0,29), and density (ρ=7800 kg/m^3). The program calculates the bulk modulus (K) using the E and ν values that were input. The yield strength $Re=425\cdot 10^6$ was used.

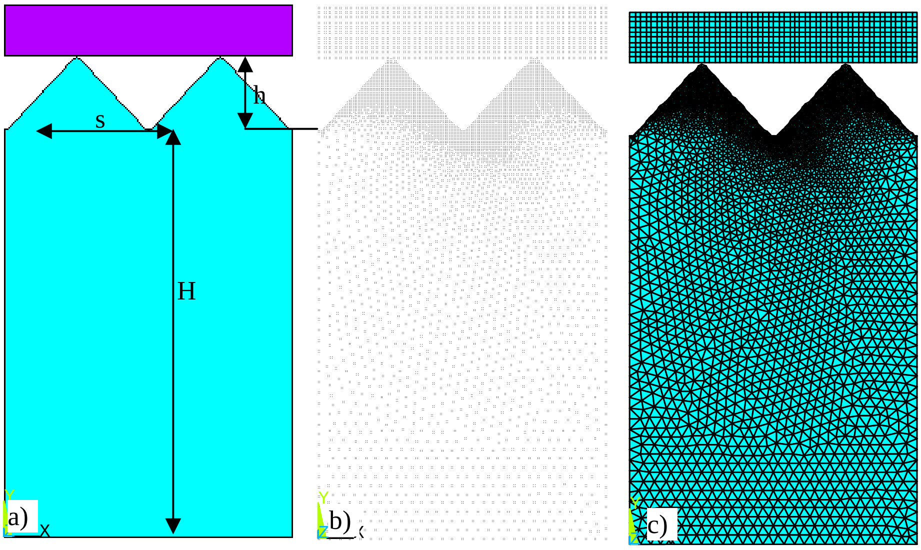


Fig.1. Model's geometry (a), view of nodes in the model (b), mesh grid (c)

4.4 Element PLANE 162 and mesh grid

The object was divided into finite element (fig. 1c). In this aim finite element Plane 162 was used. PLANE162 is used for modelling 2-D solid structures in ANSYS LS-DYNA. The element can be used either as a planer or as an axisymmetric element. The element is defined by four nodes having six degrees of freedom at each node: translations, velocities, and accelerations in the nodal x and y directions. The element is used in explicit dynamic analyses only. The geometry, node locations, and coordinate system for this element are shown in figure 2. Two different formulations are available: Lagrangian (default) and Arbitrary Lagrangian-Eulerian (ALE) [9].

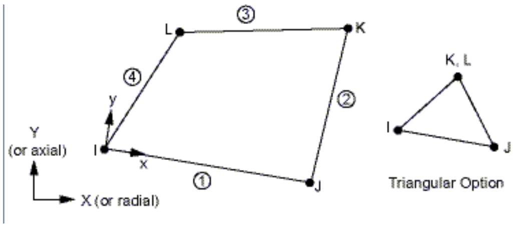


Fig.2. Characteristic of plane 162 element

It is very important to prepare sufficiently dense grid, while it has influence on the accuracy of the calculations. In considered case the grid with regular rectangle field (burnishing tool) and irregular (burnished element). There is also a possibility to concentrate the grid of finite elements in the area where strong non-linearities occur as well as to give various initial and boundary conditions.

5. COMPUTER SIMULATIONS RESULTS

The results of computer simulation: stress intensity (a), total mechanical strain intensity (b), displacement (c) and deformed mesh grid (d) for vertical angles 60÷150 [°] are presented in the figure 3÷4.

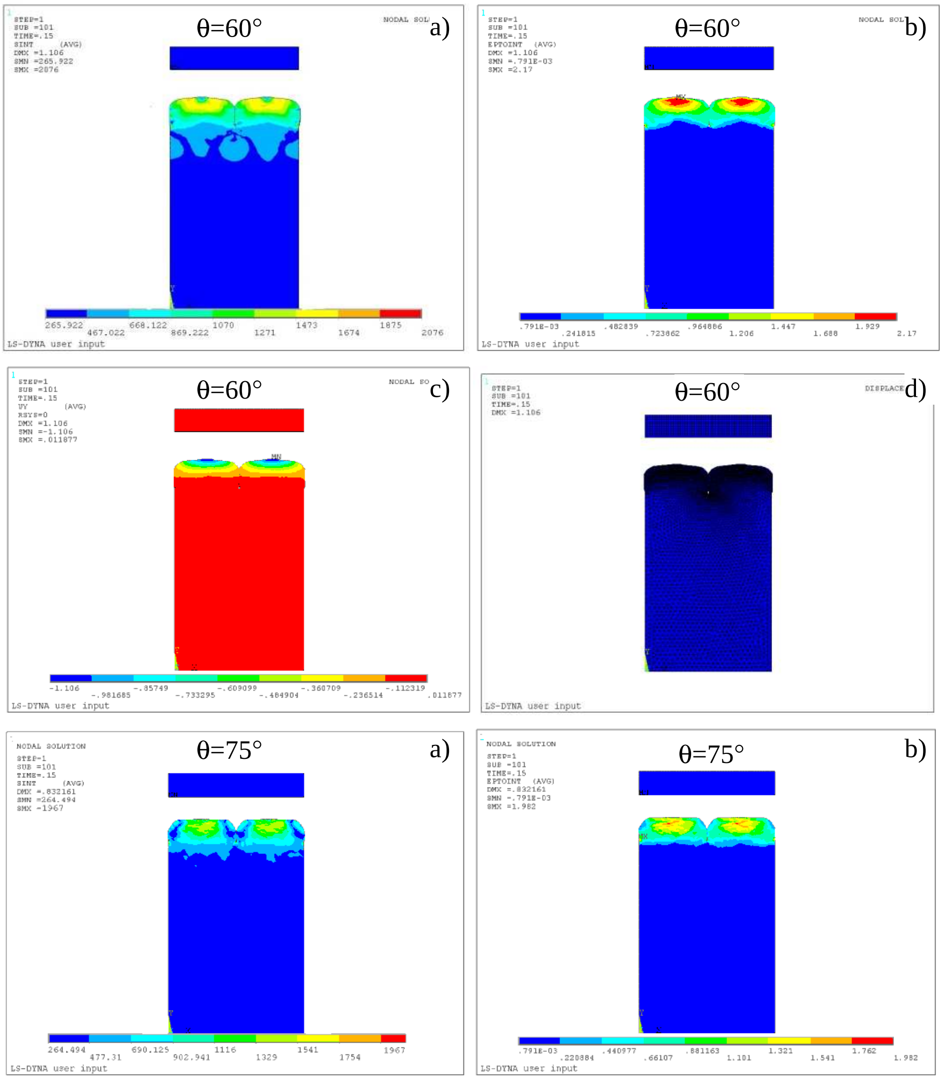
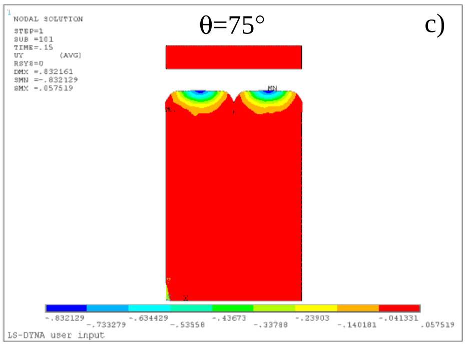


Fig.3. Results of computer simulations: stress intensity (a), total mechanical strain intensity (b), displacement (c) and deformed mesh grid (d).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SMX =.057519
θ=75°
c)
MN
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-.634429
-.53558
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-.23903
-.140181
-.041331
.057519
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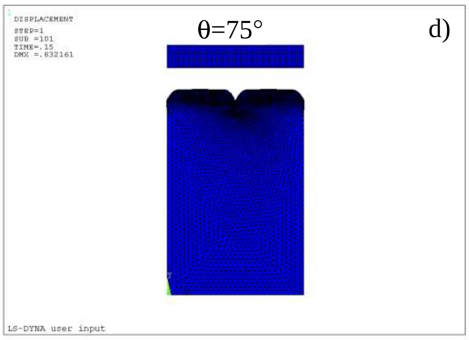
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d)
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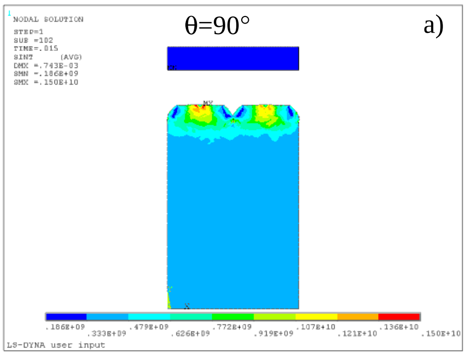
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SMX =.150E+10
θ=90°
a)
MX
.186E+09
.333E+09
.479E+09
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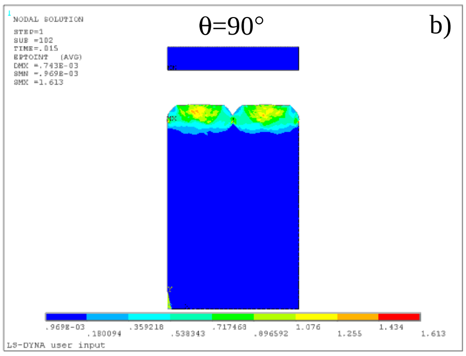
.107E+10
.121E+10
.136E+10
.150E+10
LS-DYNA user input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θ=90°
b)
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1.434
1.613
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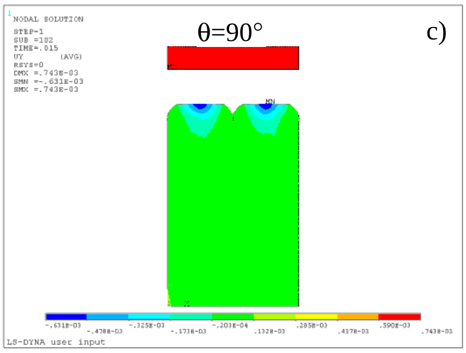
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SMX =.743E-03
θ=90°
c)
MN
-.631E-03
-.478E-03
-.325E-03
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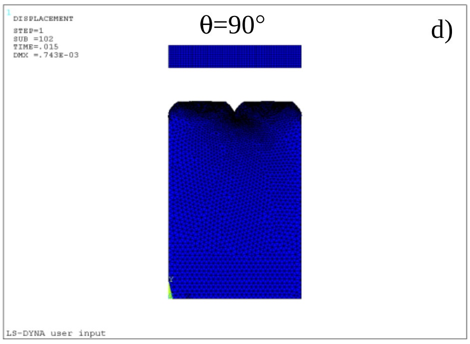
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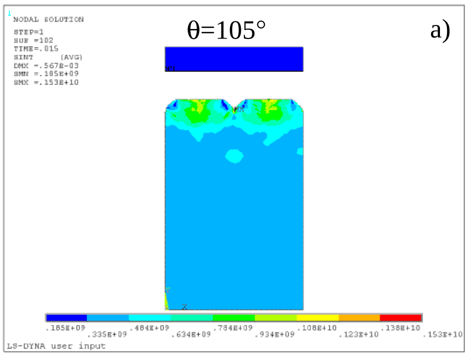
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SUB =102
TIME=.015
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SMX =.153E+10
θ=105°
a)
MX
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.335E+09
.484E+09
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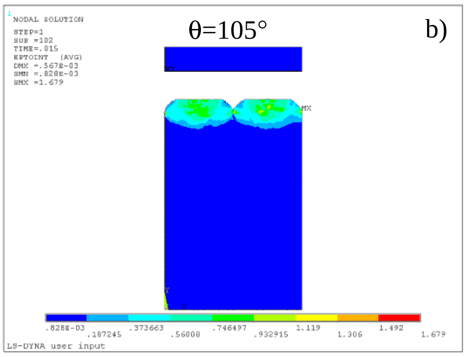
.108E+10
.123E+10
.138E+10
.153E+10
LS-DYNA user input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SMX =1.679
θ=105°
b)
MX
.828E-03
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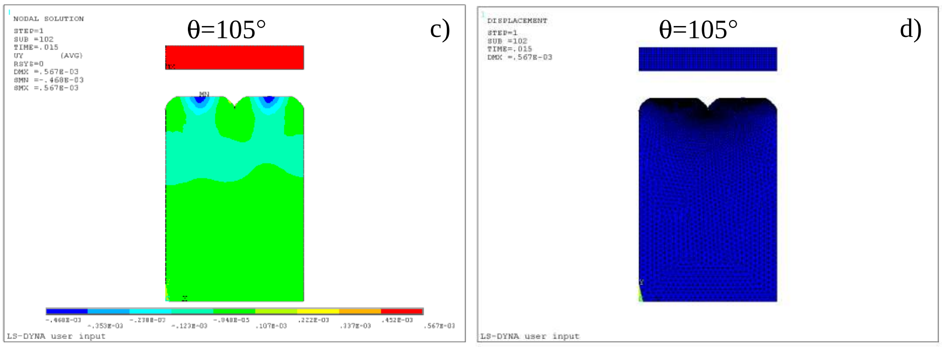
.56008
.746497
.932915
1.119
1.306
1.492
1.679
LS-DYNA user input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c)
NODAL SOLUTION
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SUB =102
TIME=.015
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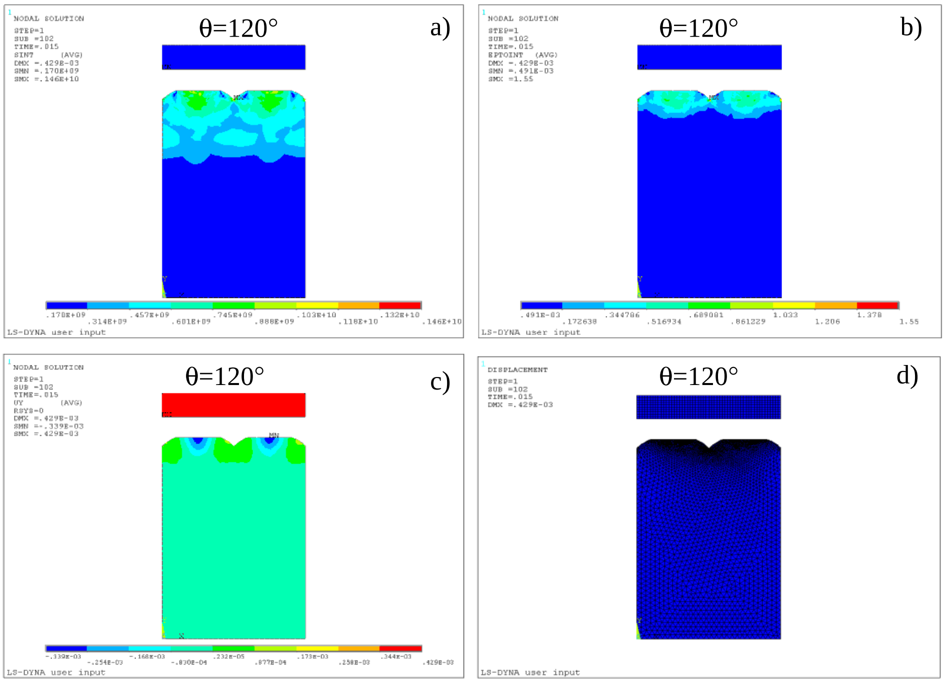
SMX =.567E-03
MN
-.468E-03 -.353E-03 -.238E-03 -.123E-03 -.848E-05 .107E-03 .222E-03 .337E-03 .452E-03 .567E-03
LS-DYNA user input
θ=105°
d)
DISPLACEMENT
STEP=1
SUB =102
TIME=.015
DMX =.567E-03
LS-DYNA user input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NODAL SOLUTION
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TIME=.015
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SMN =.170E+09
SMX =.146E+10
MX
.170E+09 .314E+09 .457E+09 .601E+09 .745E+09 .888E+09 .103E+10 .118E+10 .132E+10 .146E+10
LS-DYNA user input
θ=120°
b)
NODAL SOLUTION
STEP=1
SUB =102
TIME=.015
EPTOINT (AVG)
DMX =.429E-03
SMN =.491E-03
SMX =1.55
MX
.491E-03 .172638 .344786 .516934 .689081 .861229 1.033 1.206 1.378 1.55
LS-DYNA user input
θ=120°
c)
NODAL SOLUTION
STEP=1
SUB =102
TIME=.015
UY (AVG)
RSYS=0
DMX =.429E-03
SMN =-.339E-03
SMX =.429E-03
MN
-.339E-03 -.254E-03 -.168E-03 -.830E-04 .232E-05 .877E-04 .173E-03 .258E-03 .344E-03 .429E-03
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d)
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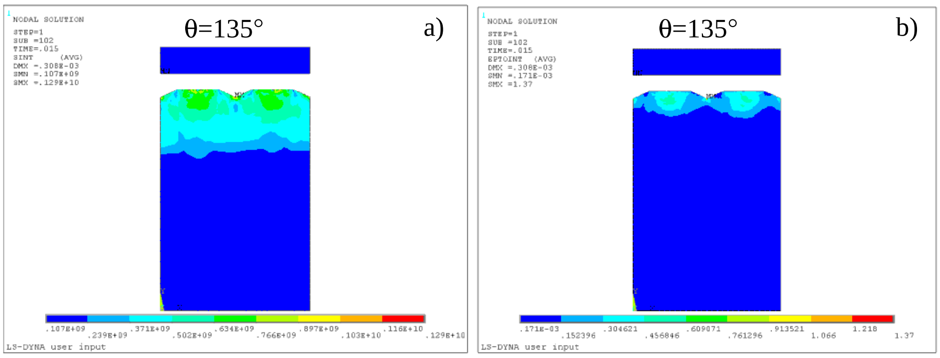
LS-DYNA user input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NODAL SOLUTION
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SUB =102
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SMN =.107E+09
SMX =.129E+10
MX
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LS-DYNA user input
θ=135°
b)
NODAL SOLUTION
STEP=1
SUB =102
TIME=.015
EPTOINT (AVG)
DMX =.308E-03
SMN =.171E-03
SMX =1.37
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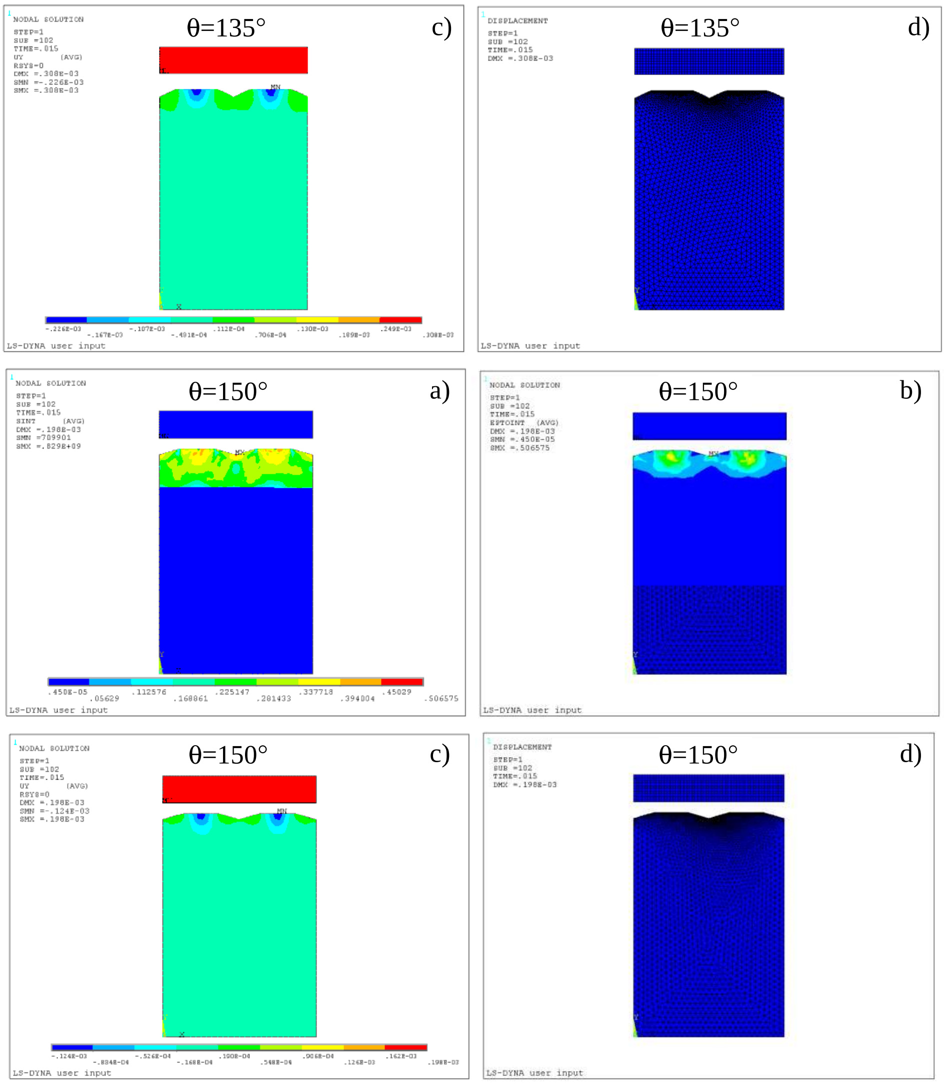

Fig.4. Results of computer simulations: stress intensity (a), total mechanical strain intensity (b), displacement (c) and deformed mesh grid (d).

6. RESULTS ANALYSYS

Received results from computer simulations allow to elaborate graphs. In the figure 5 graph of the dependence of the stress intensity after burnishing rolling from the vertical angles of asperity after turning is shown. In the figure 6 graph of the dependence of total mechanical strain intensity after burnishing rolling from the vertical angles of asperity after turning is shown.

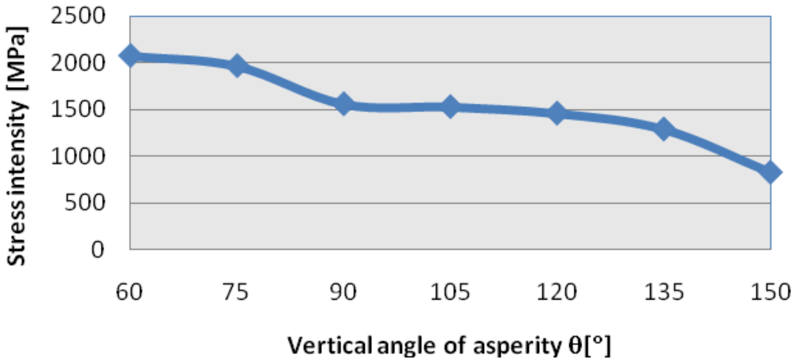

Fig.5. Graph of the dependence of the stress intensity after burnishing rolling from the vertical angles of asperity after turning.

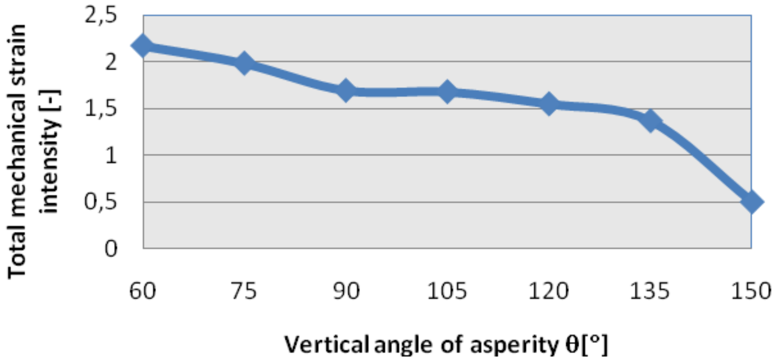

Fig.6. Graph of the dependence of total mechanical strain intensity after burnishing rolling from the vertical angles of asperity after turning.

7. CONCLUSIONS

Technological quality of surface after previous treatment in fact has deciding influence on the technological quality of the burnished product.

Elaborated applications in ANSYS/LS-Dyna system allow to analyze burnishing rolling process with taking into account real conditions of process realization. It is possible to change the vertical angles of asperities and received them like in previous treatment.

The increase of vertical angle of asperity after turning as a previous treatment cause the decrease of the stress intensities.

The increase of vertical angle of asperity after turning as a previous treatment cause the decrease of the total mechanical strain intensities.

The maximum values of total mechanical strain intensities during burnishing rolling process occurs a phenomenon excessive strains located under the surface of the material, in the so-called Bielajew point what is visible in the computer analysis results.

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