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NUMERICAL SIMULATION OF PLASTIC DEFORMATION PROCESS OF THE GLASS MOLDS CAST IRON

The most important indicator of the effectiveness of surface hardening by plastic deformation is the degree of plastic deformation of the surface layer and the remaining tensions. It is also important to understand the depth of their distribution of the surface layer and thereby determine its most dangerous sections. As well as forecasting the necessary modes for the desired result of surface deformation processing and conditions guaranteeing the non-destruction of the treated surface.
Keywords: *numerical simulation, LS-DYNA, remaining tensions, depth of distribution, numerical solution*

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КОМПЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА ПЛАСТИЧЕСКОЙ ДЕФОРМАЦИИ ЧУГУНА ФОРМОКОМПЛЕКТОВ СТЕКЛОТАРЫ

Важнейшим показателем эффективности поверхностного упрочнения при пластической деформации является степень пластической деформации поверхностного слоя и величину остаточных напряжений. Также важно знать глубину их распределения по поверхностному слою и тем самым влиять на наиболее опасные участки. А также подобрать необходимые режимы обработки для требуемой степени пластической деформации поверхностного слоя и величину остаточных напряжений, гарантирующих неразрушение обработанной поверхности.
Ключевые слова: *компьютерное моделирование, LS-DYNA, остаточные напряжения, глубина распространения, численное решение.*

1. Introduction

In the conditions of the modern trend of production, namely the constant growth of the production rate of glass containers and the increasing requirements for quality of molds become a vital search for new design solutions [1,2,3] and the search for new technological approaches to solving the problem of the quality of the surface layer while simultaneously increasing its durability. Modern molds for the production of glass containers are complex and expensive tools with a huge amount of combined machining, with a large number of different systems for vacuuming, vertical and axial cooling of various zones and sometimes special blocking of heat transfer [2, 3]. High requirements for durability of molds make it necessary to use expensive and very high quality materials such as lamellar cast iron and sometimes bronze. All these nuances make a very important scientific approach to building a process of quality improvement and ensuring high durability. The numerical simulation of plastic deformation process of the glass molds cast iron means increasing the technological capabilities of the process and its application in areas where previously it was not possible. At the same time, the application of the described method [4] makes it possible to achieve the desired result on the residual stresses in the treated layer without spending a huge amount of expensive material, using expensive equipment and a large amount of time to search for optimal modes. Without the introduction of modern computer technology, it is not possible to provide constant indicators of the quality of the processing process for different batches of materials since the area of work is very limited.

2 . Completing of simulated model.

Improving the mechanical properties of the parts and increasing the quality of plastic deformation surfaces in the smoothing process can be determined by using numerical simulation methods by thoroughly analyzing the layer in which the plastic deformations occur. The in-depth analysis of the plastic deformation layer on the smoothing operation is based on the model defined in [5, 6], with some of the improvements specified below. Under the surface undergoing the smoothing process a control layer was delineated, the thickness of which was suggested by the preliminary simulations. In these simulations, it has been found that the thickness of the plastic deformation layer by spherical head grooving does not exceed 0.8 mm, even if the radial working force takes the maximum value of 1000N. This layer, consisting of 4 rows of elements, with varying thicknesses according to the radius is shown in figure 1. The symmetry of the problem allowed the circumferential development of the control layer on a single row of elements. The control layer contains a set of control elements and a set of control nodes. The situation in detail is outlined in Figure 2 together with a very suggestive scheme of identifying the elements and control knots on the rows.

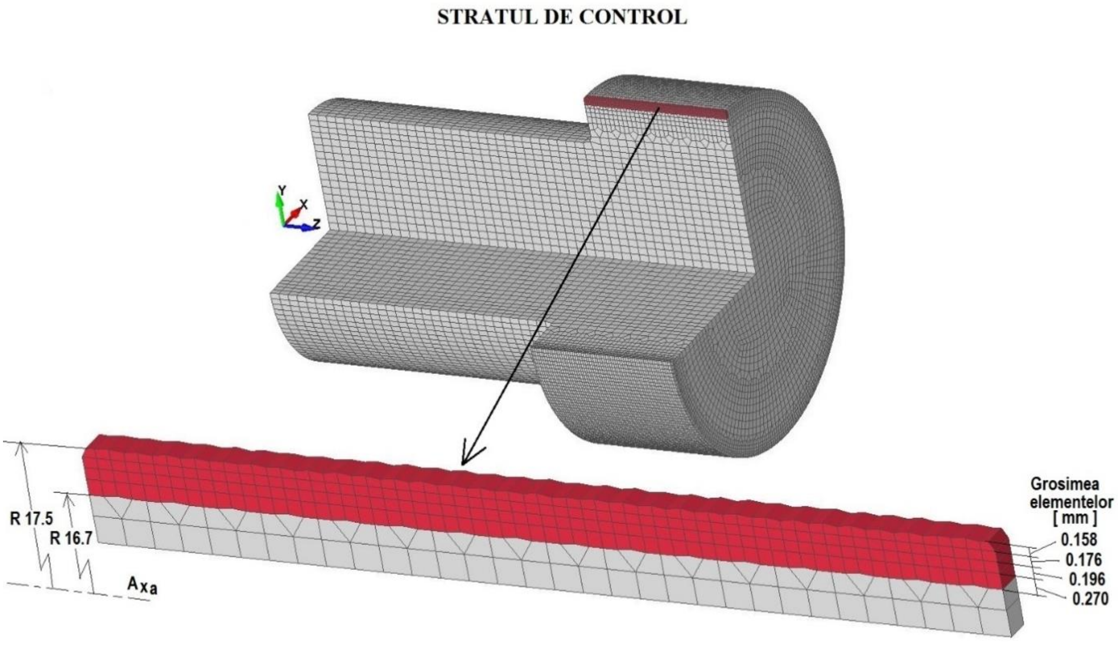

Figure 1. Control layer

In the simulation program solving algorithm - LS-DYNA - control elements and nodes occupy a privileged position. In addition to the general solution to the problem, the numerical simulations underpinning the deformed plastic layer focus particularly on the history of field functions, displacements, deformations and stresses in control elements and nodes, provided that they are declared in command file.

Initial rust on the surface subjected to processing was randomly generated, corresponding to the raw turning operation. The material model was improved by replacing the approximate Johnson-Cook with a real plastic material characteristic, determined by its own experimental determinations as outlined in Figure 3.

The material curve is also associated with the material's viscosity effect, which is most strongly felt in the tool contact area, when its spherical head passes over the material. Quantitatively, the viscosity effect is introduced by the Cowper-Symond method, with the coefficients set forth in sub: C = 7200 s-1 and p = 3.32. The flow-rate scaling method was used. The characteristic plastic curve, determined by compression tests, up to the yield limit εpl = 0.25, was added an extension that provided the material resistance up to at least εpl = 0.4. This correction is justified for the stresses that occur in the smoothing operation - compression in the three directions, as is the case with the BRINELL hardness tests analyzed in [4, 5], where the values of the actual plastic deformation over 0.4 without the material yielding.

Considering that the process benefits from optimal lubrication, the friction coefficient between the material and the sphere head of the tool was reduced from 0.08 to 0.05.

In order to increase productivity and to reduce simulation calculation effort, the axial feed was increased from 0.09 mm / turn to 0.16 mm / rot. The plastic deformed layer was analyzed by numerical simulation for two power steps, 500 N and 1000 N, following several important aspects such as:

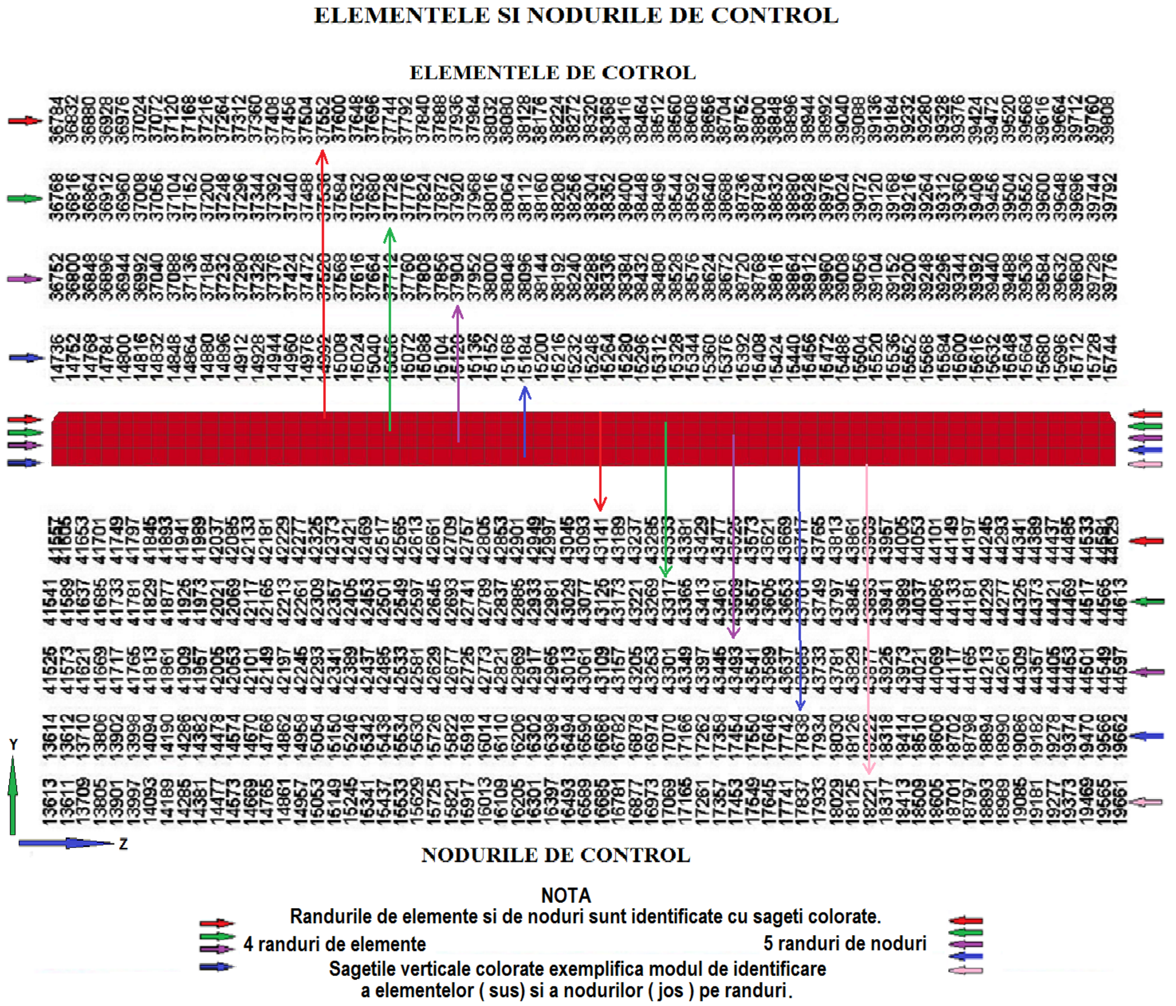

Figure 2. Control layer - control elements and nodes.

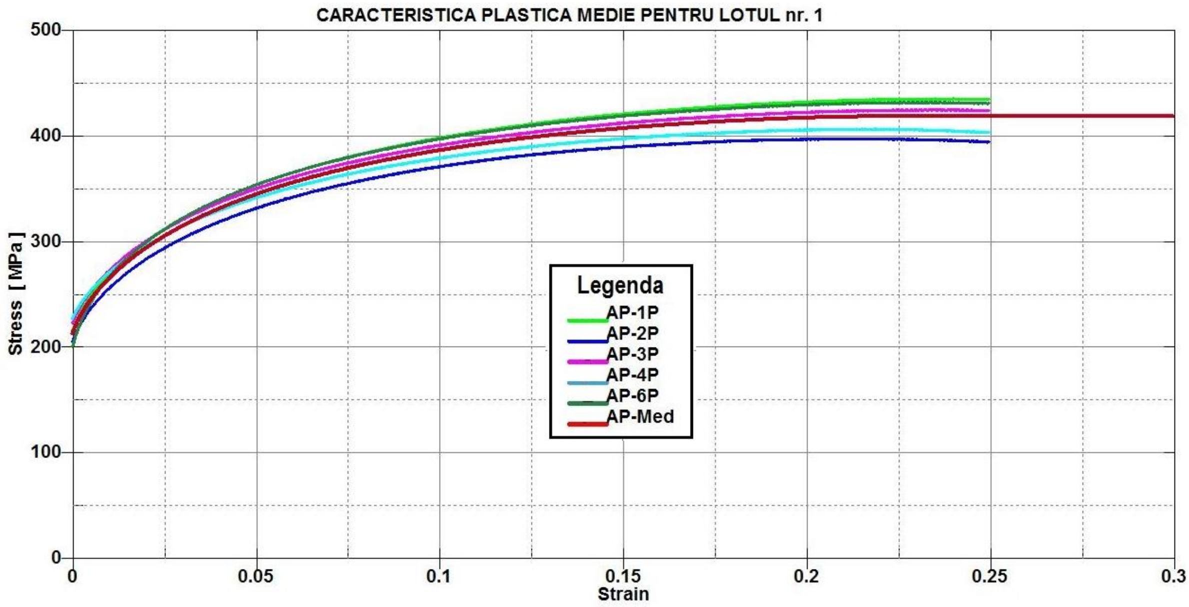

Figure 3. Average plasticity characteristic for batch no. 1

• In-depth production and development of plasticity;
• residual tensions status;
• the tensions status in the contact area;
• Improving surface quality by smoothing.

Production and in-depth development of the plasticity in the control layer
Was the analysis performed for each test case considering two deformation states an intermediate state and a final state. Figures 4 and 5 are the actual plastic deformations produced at 500 N smoothing.

It is found that in the superficial layer - the first row of elements - the field of plastic deformations is relatively inhomogeneous. One of the causes of deformation of the superficial layer with variable intensities is the presence of asperities. As plastic deformation penetrates in depth, the degree of homogeneity of the field increases.
The edge effect is obvious. The free, front surfaces of the blank give freedom of axial movement, which reduces the intensity of effective plastic deformation.

Except for the edge areas of the blank, it can be considered that the smoothing operation solves the problem of hardening of the material on the surface with a working force of 500 N. Thus, on this surface the flow tensions increases from an initial value of 215 MPa to at least 400 MPa in the weakest areas. On the detail in Figure 5 it can be noticed that the plastic deformation varies monotonously, decreasing as intensity as it penetrates into the material. For this work force, the last row of items is very little affected.

The results obtained at the 1000N force simulation, graphically represented in Figures 6 and 7, highlight the same edge effect. In terms of homogeneity, there is an improvement in the first row of elements. With 1000 N force, the hardening on the outer surface increases accordingly to a min. 420 MPa, according to the material curve.

However, this is a remarkable fact, namely that the maximum intensity of the actual plastic deformation is achieved in the substrate. On the details of the two figures we can see a concentration of effective plastic deformations at the level of the second row of nodes. In this working regime, effective plastic deformation no longer decreases monotonously by thickness, because it has a maximum in the substrate. This time, the last row of elements is also plasticized.

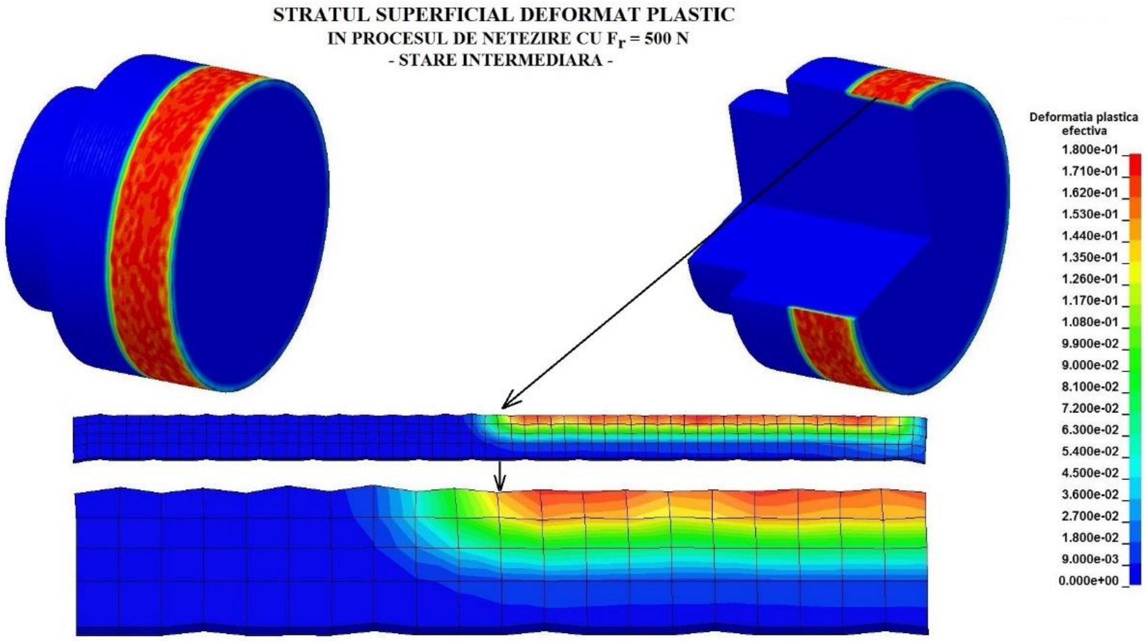

Figure 4. Superficially deformed plastic layer in the smoothing process with Fr = 500 N - intermediate state.

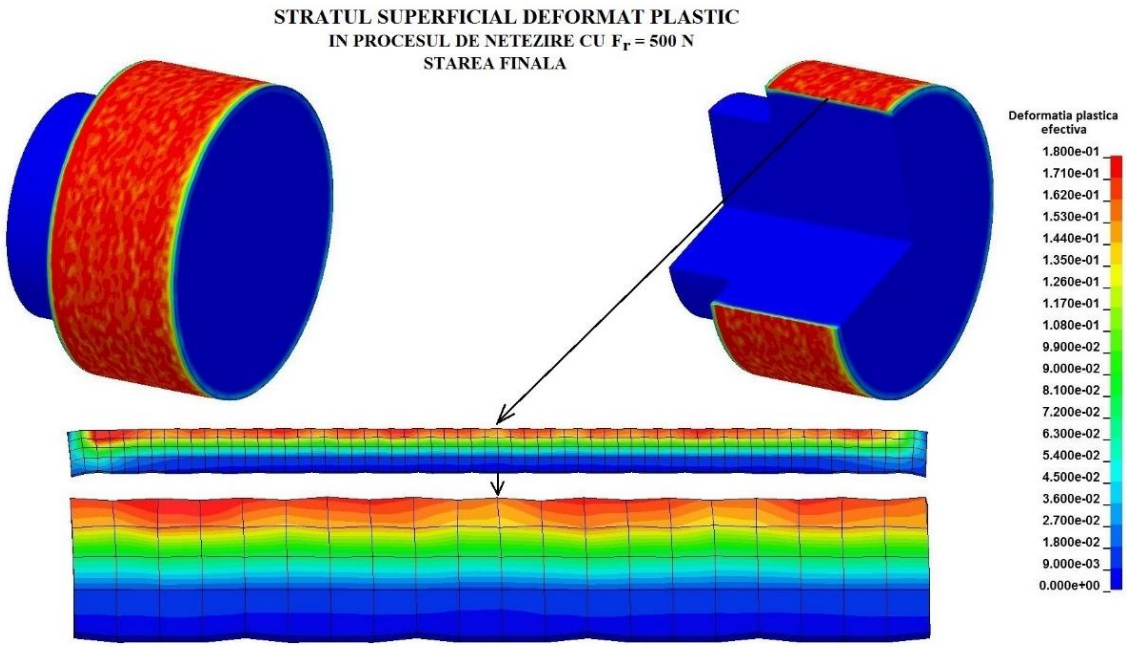

Figure 5. Superficially deformed plastic layer in the smoothing process with Fr = 500 N - final state.

The importance of having maximum values below the surface of the surface will be analyzed later on as a whole with the tensions state. Referring to the findings of the Brinell hardness test on the strength of the material in the predominantly compressive stress state, it can be determined that the plastic deformation process that occurs during the smoothing operation with forces up to 1000 N is not dangerous if ensures good lubrication.

After this analysis one can find that one of the purposes of the smoothing process - improvement of the mechanical characteristics, strength and hardness - is achieved due to the plastic deformation of the superficial layer. The higher the plastic deformations, the harder the material becomes (the ecruise is produced).

For the 4 mm radius spherical head tool, it can be determined from this analysis that 1000N force machining has the best mechanical effects without compromising the integrity of the machined parts. The production of plasticity and its evolution over time in the superficial layer of the blank can be analyzed on the graphs in Figures 8 and 9.

In these graphs the time functions of the actual plastic deformation are plotted on a part of the control elements chosen in four equidistant groups, each containing four elements per thickness. To be more suggestive, the graphs are oriented after the tool moves, the abscissa being related to the position of the center of the spherical head.

A clearer emphasis on the variation in the depth of the control layer was represented by the representation of the deformation values, not on the nodes as before, but in the center of the elements. In the representations of the fields in Figures 8 and 9, the integer element was assigned the value calculated in its center without interpolation. The analysis of these graphical representations reveals that the plastic deformations increase in stages at equal intervals with the axial feed of 0.16 mm /tur. Deformations vary only during the interaction between the elements and the ball head of the tool. In charts, the elements on the same row are represented by the same color, close to the predominant representation of the actual plastic deformation field on the elements.

Generally, charts are well grouped in color, which shows good homogeneity. As has been noted, the in-line ranges have a better homogeneity. The graphs of the two figures show much more clearly from the previous representations of the variation of effective plastic deformation over the thickness of the control layer. If the deformation decreases monotonously when machining with a work force of 500N, the highest values taken outwardly at the 1000N force processing result in a reset of the maximum values. In figure 9, it is clear from both the deformation field and the graph that the maximum values occur in the substrate, that is, at the level of the discretization adopted, in the second row. Some quantitative assessments can be made on the graph. Thus, if in the elements adjacent to the processed surface the actual plastic deformations do not exceed the value of 0.3, increments up to 0.38 are made in the next following items. As mentioned above, the problem of the increase of plastic deformation in the substrate will be addressed together with the problem of the local tension state.

3. Residual stresses in cylindrical semifinished products after the smoothing operation

For bodies with axial symmetry, the stresses in the cylindrical coordinates are relevant. The cylindrical system adopted for the representation of tensions keeps the z axis of the Cartesian system, the r and t axes being in the xoy plane, the polar angle, measured from the Ox axis, being α.

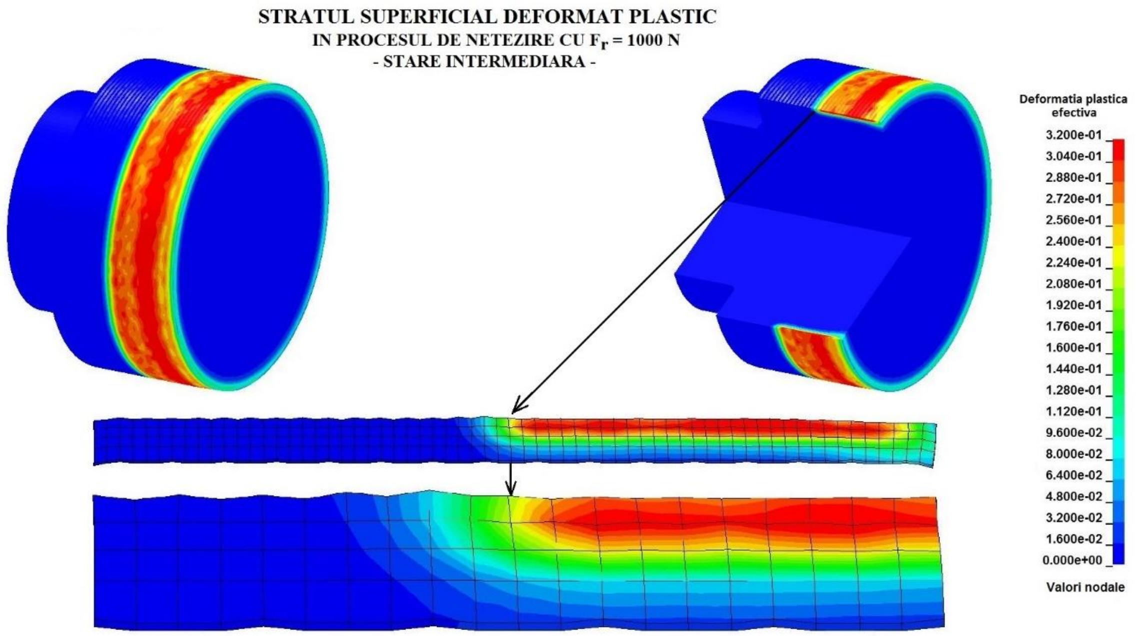

Figure 6. Superficially deformed plastic layer in the smoothing process with Fr = 1000 N - intermediate state

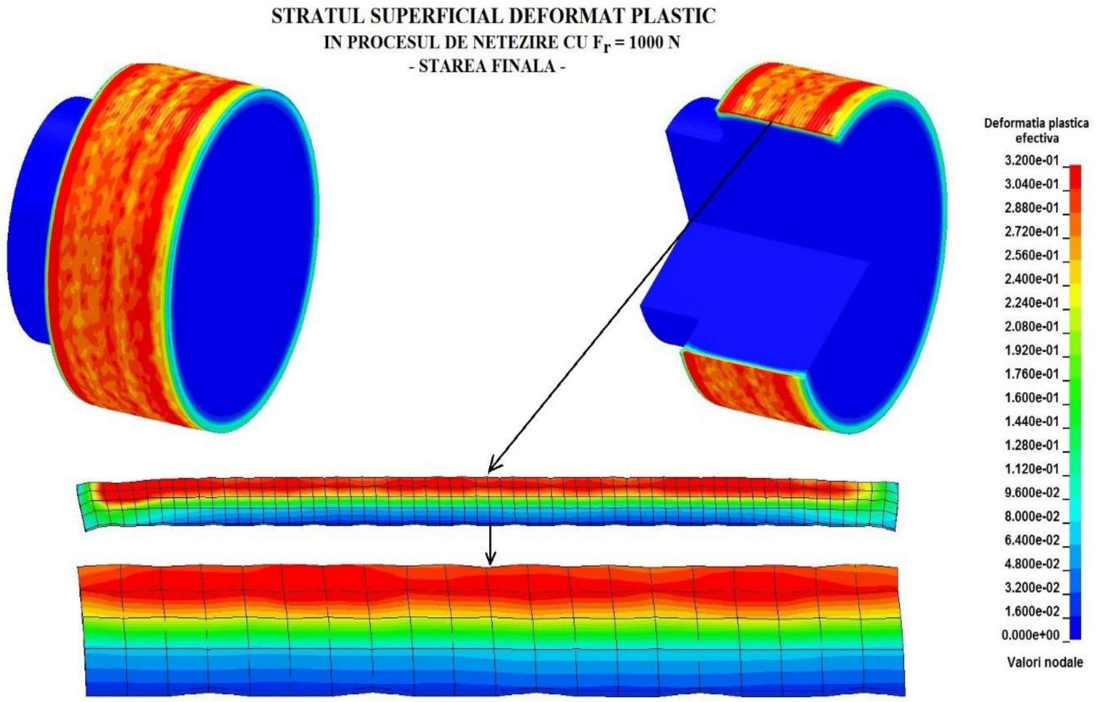

Figure 7. Superficially deformed plastic layer in the smoothing process with Fr = 1000 N - final state.

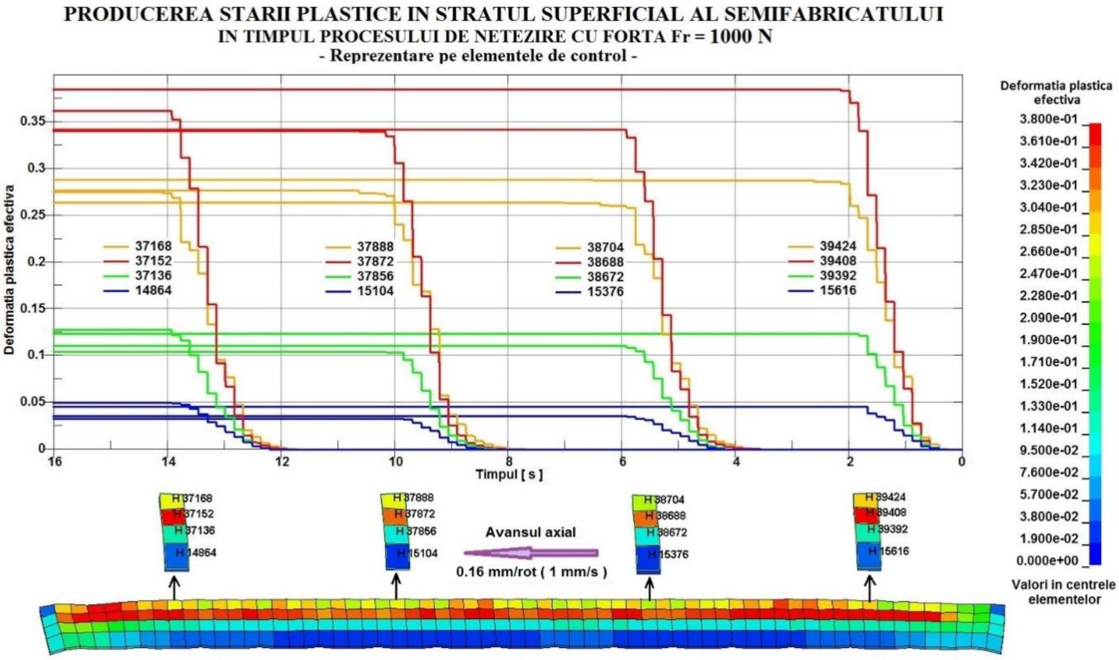

Figure 8. Production of plasticity in the superficial layer of the blank during the smoothing process with force Fr = 1000 N - representation on the control elements.

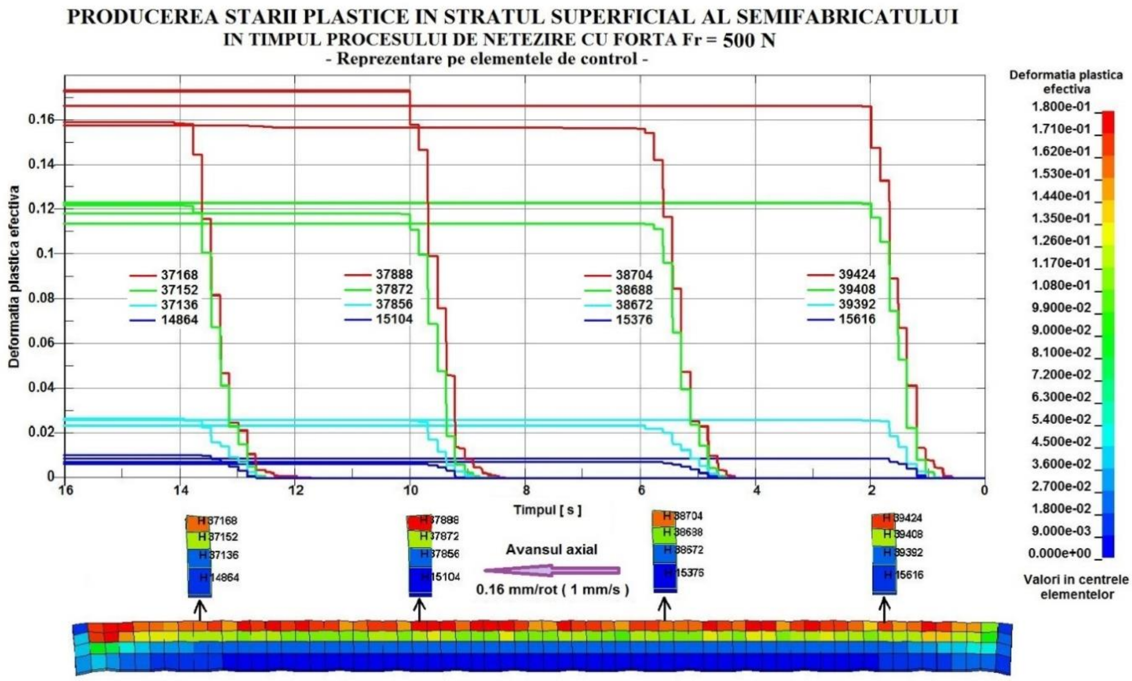

Figure 9. Production of plasticity in the superficial layer of the blank during the smoothing process with force Fr = 500 N - representation on the control elements.

The LS-DYNA code, through which numerical simulations have been performed, provides field functions in the Cartesian coordinates, for tensions σx, σy, σz, τxy, τyz, τζx.For the transformation of these tensions in the cylindrical coordinates we use the relations:

$$\sigma_r = \sigma_x cos^2\alpha + \sigma_y sin^2\alpha + 2\tau_{xy} sin\alpha cos\alpha; \quad (1)$$

$$\sigma_t = \sigma_x sin^2\alpha + \sigma_y cos^2\alpha - 2\tau_{xy} sin\alpha cos\alpha; \quad (2)$$

$$\sigma_z - remains\ the\ same\ (axial\ normal\ tension); \quad (3)$$

$$\tau_{rt} = \tau_{xy}(cos^2\alpha - sin^2\alpha) - (\sigma_x - \sigma_y) sin\alpha cos\alpha; \quad (4)$$

$$\tau_{rz} = \tau_{xz} cos\alpha + \tau_{yz} sin\alpha; \quad (5)$$

$$\tau_{tz} = -\tau_{xz} sin\alpha + \tau_{yz} cos\alpha. \quad (6)$$

In the spreadsheets, the stresses taken from the simulated solutions from the Stage_Rem-500 and Stage_Rem-1000 files and the center coordinates from the CENT-500 and CENT-1000 files were introduced. Tensions in cylindrical coordinates were calculated on columns, using relations (3).

The calculated data was eventually transferred to graphical representation files for both Sr, St, Trt, Trz and Ttz variants. The file for σ_z, Sz was taken unchanged. Residual tensions states in the blank in the cylindrical coordinates are represented in figure 10 for Fr = 500 N and figure 11 for Fr = 1000 N. In these figures, each tension has its own scale of representation. For the clarity of the images, stairs have been adjusted, rounding the values from the ends to the tens.

It is found, in the analysis of both figures, that the remaining tensions are concentrated in the vicinity of the processed surface and on it. There is a rapid decrease in tension intensity as far as the plastic deformation layer is concerned. Here, as in the case of the plasticizing layer analysis, the edge effect which negatively influences the homogeneity of the residual stresses and consequently the mechanical properties is noticeable.

For simulation with a force of 1000 N, the extreme circumferential stress in the substrate is detected, along with other previous findings in this respect. In conclusion, the tension fields remaining after the smoothing operation show that it achieves one of the main purposes in which it is applied - the superficial hardening of the material.

4. Local stress analysis

In the contact area between the sphere head of the tool and the material of the blank, a local dynamic state of tension is produced which results in elastoplastic deformations. When the local action of the contact forces ceases as a result of the movement of the two bodies, the material remains in the deformation and tension states.

The stress state analysis that produces plastic deformation is necessary to highlight some properties characteristic of elastoplastic dynamic contact.

For the analysis, an intermediate sequence of the smoothing operation (t = 6.71 s) was retained, provided that the theoretical contact point overlaps on a node of the blanket network, a condition allowing the realization of the interpretational representation sections. The analysis of this problem was done only for the case of smoothing with maximum force Fr = 1000 N. In Figure 12, in the central part, the contact pattern in action is represented. In order to

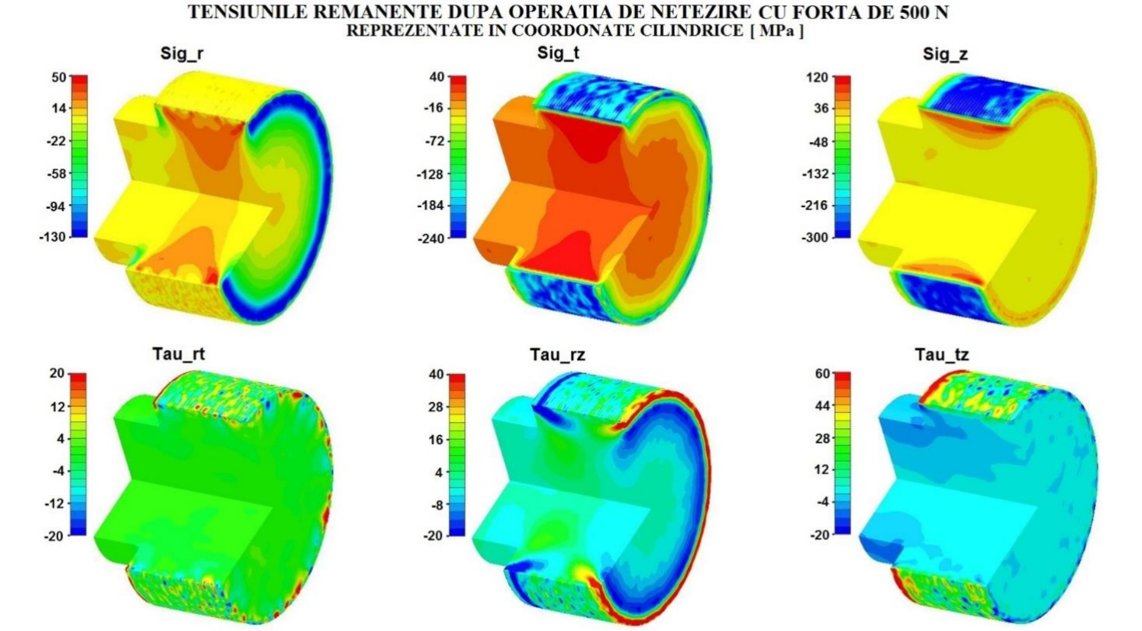

Figure 10. Remaining tensions after the 500 N force-sweeping operation represented in cylindrical coordinates [MPa]

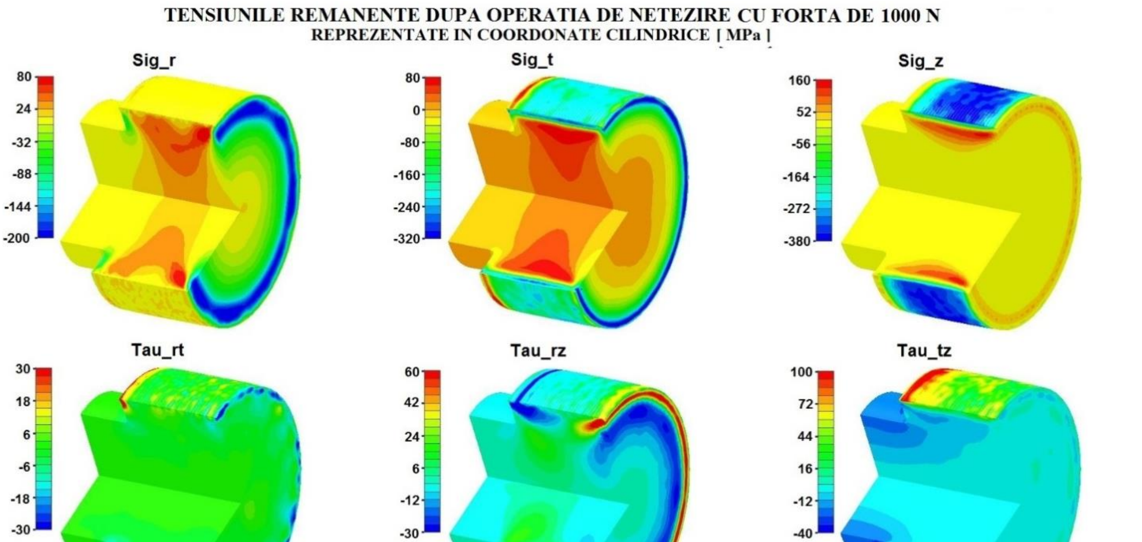

Figure 11. Rendering stresses after the 1000 N smoothing operation represented in cylindrical coordinates [MPa]

clearly illustrate the local effect of the contact, a limited portion was extracted from the sectioned piece at several rows of elements, large enough to accommodate the variation of the tensions field.

The representations of the fields of these tensions, centered on the contact, allow several conclusions to be drawn for this analysis. First, it is found that the three main stresses produce compressions in the three directions with intensities (640 MPa, 780 MPa, 1220 MPa) that exceed the unidirectional resistance of the material even three times. Working simultaneously, the three main stresses produce a hydrostatic majority state at a maximum pressure of 880 MPa. For this condition, the stresses that give resistance to the Sig_vM and Tau_max material, affected and viscosity, have the maximum values on the material curve. Consequently, for the predominantly compressive stress that occurs at the contact between the tool and the work piece, at smoothing with a force of 1000 N, respecting the conditions of good lubrication (coefficient of friction of 0.05), the resistance of the material can not be considered to be impaired.

Secondly, it can be clearly seen, on the representations of the stresses Sig_vM and Tau_max, that their maximum values are realized in the substrate. This stress distribution based on the failure criteria, effective tension and maximum tangential tension suggests the risk of milling, thawing, micro expression or short pitting. Pitting occurs under certain working conditions when the work force limit has been exceeded or when working with inappropriate lubrication, or worse, when there is no lubrication. This undesirable phenomenon occurs as a result of the relative sliding of the layers of material, mainly produced by the maximum tangential stress. When this size exceeds the yield value, particulate matter is released in the form of scales. This explanation, as a consequence of the numerical simulations, supports the experimental finding of the grinding of the processed surface when the working regime is out of the parameters. In preventing pitting, proper lubrication plays a determining role.

Another finding, visible on the larger scale representations in Figure 12, is to improve the surface quality of the surface by smoothing. A quantitative approach to this effect will be made in the next paragraph. With the evaluation of the surface quality subjected to the smoothing process, the analysis by numerical simulation of the plastic deformed layer ends with the following conclusions:

• the smoothing process applied to the cast iron parts has the effect of increasing mechanical properties on the surface, making them more resistant to mechanical stresses and wear;

• by smoothing the roughness is greatly reduced and consequently interaction between the parts subjected to this process and the conjugate medium (e.g., the glass paste) is done with reduced friction forces, thereby reducing adhesion;

• Under certain working conditions, pitting can occur during the smoothing process. This undesirable phenomenon can be avoided by limiting work forces and providing optimal lubrication;

• Some measures are required to reduce the edge effect such as: rounding or edging of edges, strength control, design of continuous and smooth shapes.

5. Conclusion

1. In these simulations, the maximum thickness of the deformed plastic layer by spherical smoothing is found to be very thin and does not exceed 0.8 mm, even if the radial work force takes the maximum value of 1000N.
2. This simulation highlights a remarkable fact, namely that the maximum intensity of the actual plastic deformation is achieved in substrate causing exfoliation.
3. Two-fold increase in processing power (from 500 N to 1000 N) provides flow tensions increases only 5 percent.
4. This simulation makes it possible to estimate as a percentage the numerical value of the actual plastic deformations.

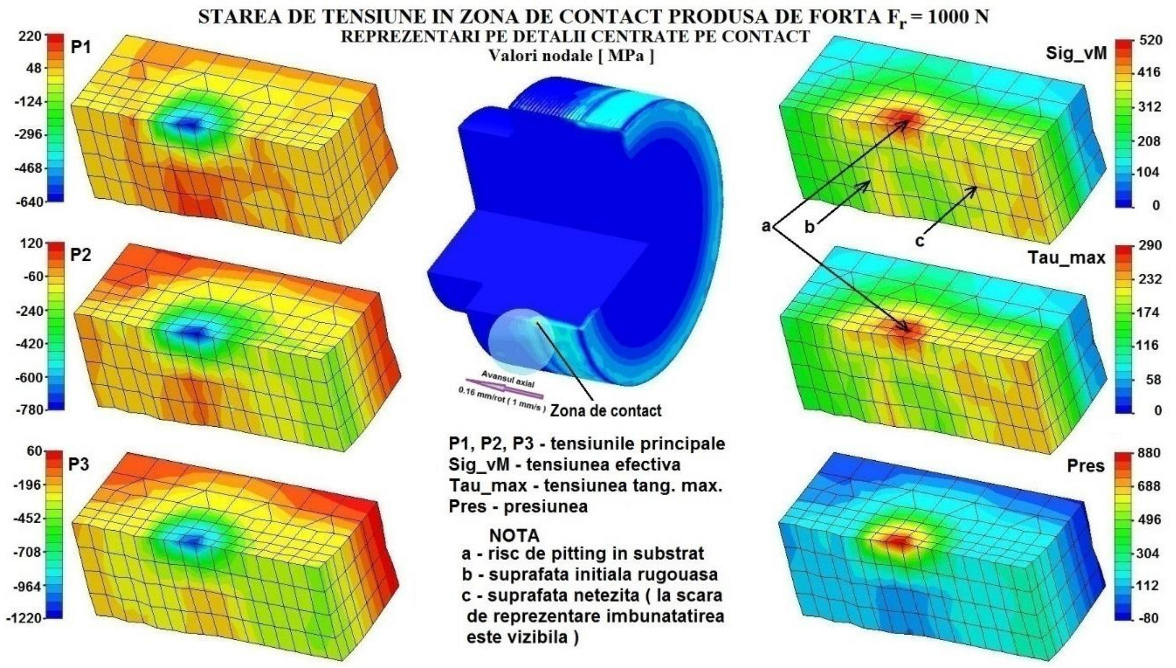

Figure 12. Tension state in the contact area produced by the force Fr = 1000 N - representations on details centered on the contact [MPa].

REFERENCES:

1. Cosovschi P. Îmbunătăţirea răcirii componentelor seturilor de forme pentru formarea sticlelor // Buletinul institutului politehnic din Iaşi. – 2008, vol liv. – p. 45-48.
2. Mazuru Sergiu, Cosovschi Pavel. Brevet Nr. MD 4143. Dispozitiv pentru turnarea produselor din sticlă prin metoda de aspiraţie cu vacuum, B2 2011.12.31.
3. Mazuru Sergiu, Cosovschi Pavel. Brevet Nr. MD 358. Echipament de prefasonare pentru maşina automată de formare a produselor din sticlă cu gât îngust, Y 2011.04.30.
4. Chereches T., Lixandru P., Mazuru S., Cosovschi P., Dragnea D. Numerical simulation of plastic deformation process of the glass mold parts // „Applied mechanics and materials”. – vol 657. – pp 126-131. – 2014 trans tech publications, Switzerland.
5. Chereches T., Lixandru P., Mazuru S., Cosovschi P., Dragnea D. Numerical simulation of plastic deformation processes from cast iron parts, Academic journal of manufacturing engineering, 2014. – vol. 12. – issue 2. – p. 29-36.
6. Cosovschi P. Simularea numerică a procedeelor de netezire şi de durificare// Fizica şi tehnică, 2013. – vol.2. – p. 28-33, or.Bălți.

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