IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Numerical modeling of pipe parts of agricultural machinery expansion by stepped punches

To cite this article: R H Puzyr *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1018** 012013

IOP Conf. Series: Materials Science and Engineering **1018** (2021) 012013 doi:10.1088/1757-899X/1018/1/012013

Numerical modeling of pipe parts of agricultural machinery expansion by stepped punches

R H Puzyr[1], V T Shchetynin[2], R H Arhat[2], Yu B Sira[1], V V Muravlov[3] and S I Kravchenko[3]

[1] Kremenchuk Mykhailo Ostrohradskyi National University College, Chumatskyi Shliakh str. 7, Kremenchuk 39621, Ukraine
[2] Kremenchuk Mykhailo Ostrohradskyi National University, Pershotravneva str. 20, Kremenchuk 39600, Ukraine
[3]Poltava State Agrarian Academy, Skovorody str. 1/3, Poltava, 36003, Ukraine

E-mail: puzyruslan@gmail.com

Abstract. The paper presents the research of plastic expansion of a pipe workpiece by punches of various configurations. It is shown that interest in this process is caused by the development of oil production, where there is a need to increase the diameter of well pipes, the automobile industry, where the protection of the driver and passengers in case of accidents comes first. Here, stable plastic deformation plays an important role as a good absorber of kinetic energy, etc. Data on the problems of expanding pipe ends are given, where special attention is paid to the destruction of the end in the form of localization of deformations and appearance of a longitudinal crack. To eliminate this phenomen onvarious technological methods are used. Here the influence of the design and shape of the punch on the localization of deformations along the thickness of the workpiece is researched. Several spatial outlines of the tool are proposed to create an effective reloading of the pipe workpiece in the deformation zone. Based on numerical modeling, the distribution of stresses according to Mises, the displacement of the end of the semi-finished product and logarithmic deformations in the radial direction is shown for each standard size of the punch. Comparative results reveal an increase in the thickness of the workpiece in the dangerous section for all presented punches. The comparison was carried out with a reference tool that has a straight generatrix of a tapered surface. The best results are shown by a punch with an enlarged generatrix at the end of the working stroke. Attention is focused on conducting further research in order to study the possibility of overcritical deformation by the proposed tool.

1. Introduction

Tubular metal parts are widely used in the structure so mechanism so ships, automobiles, airplanes, spacecraft, electrical appliances, household and agricultural devices. Normal functioning of the oil and gas production and oil refining, chemical, food, engineering and agricultural industries of any country is unthinkable without pipelines. Pipe parts are also used in the construction industry as various types of connecting elements and power welded structures.

To obtain a strong pipe connection from pipes of different diameters, adapters or expansion of the ends of pipes of a smaller diameter are used. This operation in cold forming is called expansion. And although the first scientific substantiation of this process was given more than 70 years ago by R. Hill

[1], where the influence of the main parameters of the expansion on the distribution of stresses and deformations in the selected section of the workpiece was considered, the task of further studying and improving the expansion remains relevant at the moment. This is facilitated by the steady development of oil and gas production, where expansion is used to increase the passage of well pipes using the Solid Expandable Tubular (SET) technology [2, 3] or for the conservation of oil wells [4, 5]. An intensive subject of research is the improvement of the passive protection of the automobile in a collision with an obstacle, where plastic deformation of the tubular body elements by expanding and bending acts as an effective absorber of kinetic energy [6, 7]. Similar tubular stabilizers are used for soft landing of spacecraft and aircraft [8, 9]. Heat exchangers are widely used in the world, and their designs are constantly being improved. They are used into hold and industrial ventilation and air conditioning systems [10], in the food and oil refining industries as heaters and evaporators [13, 14], in refrigeration systems for ships, railway transport and agricultural machinery [11,12]. The expansion operation is used here when connecting the tube soft the tube bundle with the tube plate to seal the intertubular space [15].

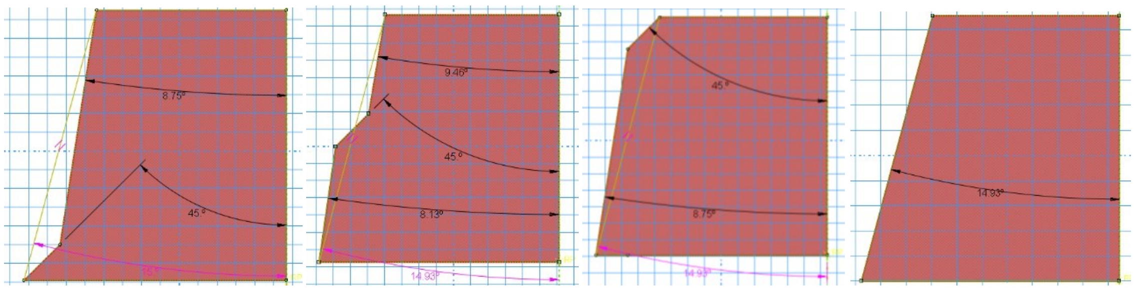
In the above examples, researchers solve various problems that are inherent in the chosen research subject. Reducing the expansion force when pushing the ferrule through the well pipe. The solution is achieved by reducing the coefficient friction between the tool and the pipe by using modern lubricants, as well as by varying the geometry of the tool. The influence of the geometry of the tool and the coefficient of friction on the expansion force was considered in papers [16-18]. In research on the protection of automobile occupants in a collision, expansion is analyzed in the context of the stability of the plastic deformation process. A number of papers are devoted to this problem [19-21]. When coupling the tubes with the tube plate of the heat exchanger, it is important to take into account the joint deformation of the tube and the plate in order to obtain a tight connection. This is achieved by tool geometry and deformation rate control. [22, 23].

It should be especially noted that with an increase in the degree of deformation of a pipe workpiece, in some cases, processes of localization of deformations at the end of a semi-finished product can occur with the subsequent appearance of longitudinal cracks and destruction, which is not permissible from the point of view of quality.[24]. Therefore, the efforts of researchers are aimed at studying various factors of expansion that affect the increase in the degree of deformation without loss of stability and destruction of the workpiece. Analytical dependences and numerical results of research are proposed, which make it possible to assess the influence of the initial and acquired anisotropy on the stability of the plastic deformation process [25, 26], the geometric dimensions of the workpiece and the taper angle of the punch [27-29] on crack formation and the formation of a longitudinal fold on the non-deformable part of the workpiece. Numerous methods of supporting the end of the workpiece during expansion and changing the rectilinear shape of the generatrix of the conical surface of the tool to increase the degree of deformation are also presented.[30-32]. Therefore, the purpose of this paper is to numerically model the process of expansion by conical punches of various spatial configurations, compare the modeling results, develop recommendations and substantiate further areas of research.

2. Research Methodology

The desire of researchers from various scientific schools to increase the degree of deformation of a cylindrical workpiece in one pass of the punch results in a complication of the design of the latter, excessive consumption of additional materials or an increase in the duration of the part manufacturing cycle. The creation of triangular or toroidal surfaces on the straight generatrix of the punch, which reduce the contact area of the workpiece and the tool and facilitate the lubrication conditions, leads to a rather laborious process of manufacturing such a tool [31, 32]. The additional support of the end face in the form of retaining rings complicates the design, and the support in the form of rings made of easily deformable alloys leads to the consumption of this additional material. This increases the technological cost of the operation [30, 33].

To study the process, three types of punches were proposed. They differed in the location of the transition step along the generatrix of the tapered part. The results of the numerical experiment were compared with each other, as well as with the reference version of expansion, where a punch with a straight generatrix of a cone acted as a tool. For all variants, the material and dimensions of the work piece were identical. A material such as aluminum 5005 with the following mechanical characteristics was modeled: yield point $\sigma_{0.2}$=50 MPa; ultimate strength σ_v=110 MPa; Young's modulus E=70 GPa; Poisson's coefficient ν=0.33, density ρ=2700 kg/m^3. An elastoplastic isotropic model of the material with isotropic hardening was taken, the diagram of the true hardening curve was approximate in the form of $\sigma_{0.2}=50+0.64\varepsilon^{0.62}$ [34, 35]. That is, the following assumptions were made: the initial and acquired anisotropy in different planes was absent; during deformation the material was strengthened equally in all coordinate directions. The workpiece external diameter D_0= 25 mm, wall thickness s_0= 2 mm, height h_0= 50 mm. The geometrical dimensions of the reference punch: larger taper diameter D_p= 29 mm, the height fo the taper part H_p= 15 mm, the angle of the generatrix of the cone to its axis of symmetry $\alpha\approx15°$.The expansion ratio was k = 1.38. This parameter was chosen in accordance with the recommendations [36, 37] and ensured stable expansion without loss of stability and destruction of the workpiece end. The geometry of the stepped punches was varied so that the broken generatrix coincided with the points of the beginning and end of the generator of the reference punch and α_1=45° for all stepped punches (figure 1).



a) b) c) d)

Figure 1. Sections of 1 \ 2 part of punches for expansion: a) a punch with a protrusion at the end of the tool stroke α_1=45°, $\alpha_2\approx$ 9°; b) a punch with a protrusion in the middle part of the generatrix of the toolα_1=45°, $\alpha_2\approx$ 9.5°, $\alpha_3\approx$ 8°; c) a punch with a protrusion at the beginning of the tool working strokeα_1=45°, $\alpha_2\approx$ 9°; d) a reference punch with an inclined taper generatrix α_1=15°.

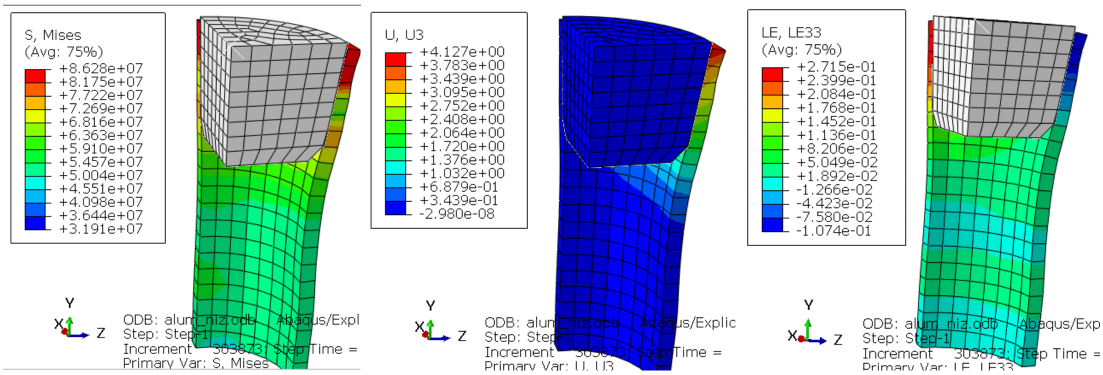
Finite element modeling was carried out in the applied complex Simullia Abaqus - student edition, which is supplied by "TESIS" in the free access and only limits the number of finite elements in the assembly of the model [38].

The tool and workpiece were modeled in a 3D setting by the rotation method. Moreover, since the problem is axisymmetric, ¾ share of the part and the punch participated in the assembly. To imitate the deformation process in each problem, a velocity equal to v=2.5 mm/sec directed along the axis of the cylinder was applied to the punch, which was represented as an undeformable solid [39, 40]. Also, the loading conditions were modeled by setting boundary conditions in displacements, while the lower end of the workpiece was fixed during the entire loading period, which modeled a rest against a rigid base, the ends of the workpiece were limited in displacements along two axes and rotations also along two axes, and on the side surfaces and the upper end were restricted in rotation around the axis, which coincides with the axis of symmetry of the workpiece..One of the main assumptions of the problem was the friction between the workpiece and the tool, which was taken in mechanical constants in a kinematic formulation with the final formulation of the contact and the coefficient of friction equal to k_t= 0.1. The coefficient of friction was chosen on the basis of the data of works [15, 18, 36], as well as production experience when distributing cylindrical billets made of aluminum. It takes this value when lubricating tools with industrial oil.

When generating a finite-element grid for the tool, the free method of its construction was determined and the element type R3D4 was selected, setting the bilinear order of the element that is contained in the standard library from the category of solid quadrangular ones. A hexahedral form was chosen for the workpiece, expansion was taken as the method of its creation, element C3D8R with the linear order from the standard library, category 3D Stress, i.e. operating in all three directions across the whole volume was selected.

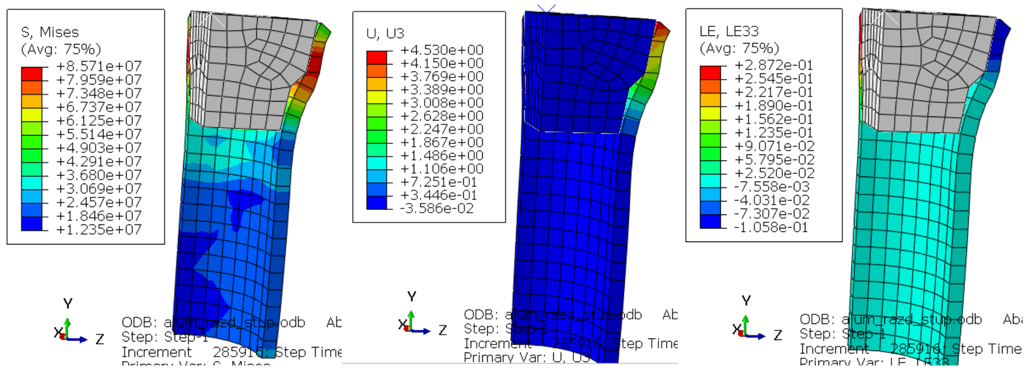
3. Results

The results of modeling the expansion process are shown in figures 2, 3, 4, 5. The figures contain diagrams of stress fields according to Mises, displacements of the upper edge of the workpiece and logarithmic deformations of the end of the cylinder at the end of the working stroke of the tool for each standard size of the punch.



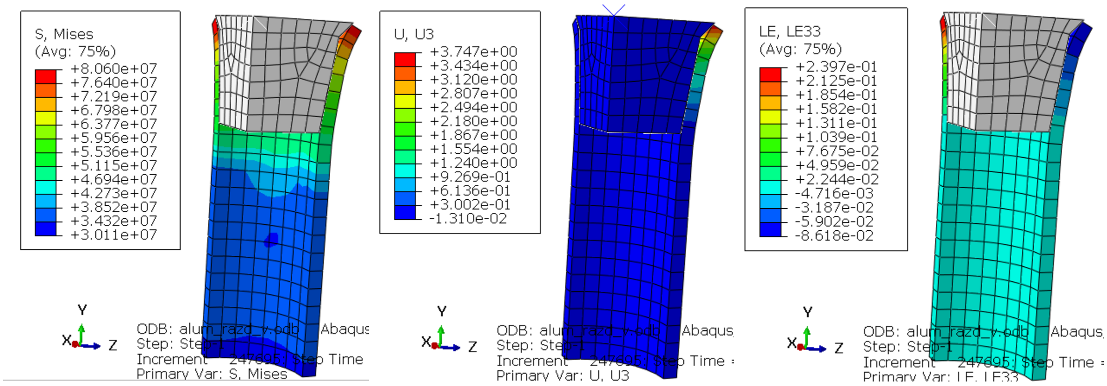
a) b) c)

Figure 2. Diagrams of deformation parameters at the end of the punch working stroke with alow tooth arrangement: a) stress distribution according to Mises; b) displacement distribution; c) distribution of logarithmic deformations.



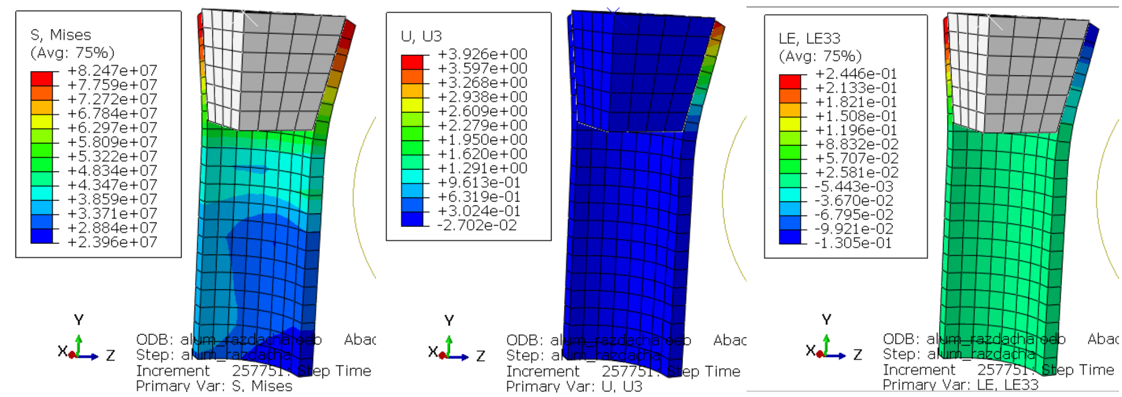
a) b) c)

Figure 3. Diagrams of deformation parameters at the end of the punch working stroke with a middle tooth arrangement: a) stress distribution according to Mises; b) displacement distribution; c) distribution of logarithmic deformations.



a) b) c)

Figure 4. Diagrams of deformation parameters at the end of the punch working stroke with a middle tooth arrangement: a) stress distribution according to Mises; b) displacement distribution; c) distribution of logarithmic deformations.



а) б) в)

Figure 5. Diagrams of deformation parameters at the end of the punch working stroke of the reference punch: a) stress distribution according to Mises; b) displacement distribution; c) distribution of logarithmic deformations.

Comparison of the given diagrams reveals that the greatest Mises stresses affect the edge part of the tubular workpiece in all variants, except for expansion by a punch with the tooth located in the center of the tool. Here the middle part of the semi-finished product is subjected to the greatest stresses. The largest value of equivalent stresses according to Mises σ_i=86.2 MPa belong to the workpiece, which is deformed by a punch with a low tooth arrangement, the workpiece that is deformed by a punch with an upper tooth arrangement has the smallest value – σ_i=80.6 MPa. The movement of the end of the workpiece in the direction perpendicular to the axis is the greatest for the workpiece, which is deformed by a punch with a middle tooth location U = 4.5 mm, the smallest - U = 3.92 mm is for the workpiece, which is expanded by the reference punch. The largest logarithmic deformations, which indicate a decrease in the thickness of the workpiece, occur, as expected, at the end. The workpiece end loaded by the reference punch is subject to the greatest deformations ε = 0.13, the end of the workpiece which is deformed by a punch with an upper tooth location is subject to the smallest deformations ε = 0.086.

Also, an interesting result of the research consists in the fact that during expansion by a punch with a step in the middle of the generatrix, the zone of the middle part of the workpiece is subject to the highest equivalent stresses according to Mises, where σ_i=85.7 MPa, while at the end, where the greatest stresses are to be expected, they are less than σ_i=67.4 MPa. This indicates that the semi-finished product receives the main deformation of the expansion in the middle zone, passing the step of a sharp increase in the diameter, and when approaching the upper end of the punch practically does not experience plastic deformations. As figure 3 demonstrates, the edge section of the semi-finished product does not come in to contact with the punch wall, having received a greater expansion at the punch step. This is evidenced by the largest displacement of the end face U = 4.5 mm.

4. Conclusions

The research results presented in the previous section lead to certain conclusions. The nature of the Mises stress distribution, where the highest stresses act on the end of the semi-finished product, is similar for all loading options, except for deformation by a punch with a step in the middle part of the conical surface generatrix. However, their value is not the same. For a punch with a step at the top, it is 2% less, and for a punch with a step at the bottom, it is 4% more in comparison with the results of deformation by the reference tool. The displacements of the end surfaces of the workpiece, which indicate its increase in diameter, are practically equal to U≈4.0 mm, except for deformation by a punch with a step in the middle part. This suggests that the workpieces receive the planned degree of expansion with the coefficient k = 1.38 and the semi-finished product end bears against the tool at the end of the working stroke. This result does not apply to the above case. However, the logarithmic deformations acting in the radial direction and indicating a decrease in the thickness of the workpiece differ significantly from each other. For a punch with a step at the top of the generatrix, they are 32% less, and for a punch with a step at the bottom, they are 18% less compared with identical deformations obtained with the reference punch. This fact indicates the positive effect of the step on the amount of thinning in the dangerous section of the workpiece. The step of a sharp change in the diameter of the tool creates a sharp jump in stresses during deformation, which imitates the support of the end of the workpiece, which leads to an increase in the thickness of the end part of the semi-finished product. This fact will make it possible to use the stepped punches for expansion within the established intervals of a steady expansion process. The next stage of research can include the modeling of the expansion with a stepped tool beyond the boundaries of the process stability, so the thickness margin of the workpiece metal makes it possible to predict such a possibility.

As for the results of the research on loading with a punch with a step in the middle part, a decrease in stresses at the end of the workpiece at the end of the working stroke is of interest. In this case, the logarithmic deformation in the radial direction at the end is 19% less than in the reference version. This indicates presence of a rest on the side of the step, but it is not as effective as a punch with a step at the upper part.

The following recommendations could be given for production: use punches with a step at the top for distributing the ends of pipe blanks. This tool design gives the best result in terms of increasing the thickness of the finished part at the end. This, in turn, can reduce the weight of the structure, since the initial blank will be thinner.

References

[1] Hill R 1950 *The Mathematical Theory of Plasticity. Oxford University Press* (New York)
[2] Al-Abri O S and Pervez T 2013 Structural behavior of solid expandable tubular undergoes radial expansion process – Analytical, numerical, and experimental approaches *International Journal of Solids and Structures* **50** 2980-94
[3] Pervez T 2010 Experimental and numerical investigations of expandable tubular structural integrity for well applications *J. Achiev. Mater. Manuf.* **41** 147-154
[4] Pervez T and Qamar S 2011 Finite element analysis of tubular ovality in oil well *Advanced Materials Research* **264-265** 1654-59

[5] Sanchez F and Al-Abri O 2013 Tube expansion under various down-hole end conditions *The Journal of Engineering Research* **10** 25-40
[6] Drusina N, Mahapatra R, Abdul-Latif A, Baleh R, Wilhelm C, Stoyanov P and Es-Said O 2008 Microstructure Analysis of Aluminum Alloy and Copper Alloy Circular Shells After Multiaxial Plastic Buckling *Mechanical Engineering Faculty Works* **17** 755-766
[7] Baleh R and Abdul-Latif A 2016 Quasi-Static Biaxial Plastic Buckling of Tubular Structures Used as an Energy Absorber *Journal of Applied Mechanics* **74** 628-635
[8] Jialing Yang, Min Luo, Yunlong Hua and Guoxing Lu Energy absorption of expansion tubes using a conical–cylindrical die: Experiments and numerical simulation *International Journal of Mechanical Sciences* **52** 716–725
[9] Alves M, Almeida B, Rosa P and Martin P 2006 End forming of thin-walled tubes *Journal of Materials Processing Technology* **1** 177–183
[10] Xiaowen M, Dian-ce G and Dong L 2017 Improved Control Strategy of Variable Speed Pumps in Complex Chilled Water Systems Involving Plate Heat Exchangers *Procedia Engineering* **205** 2800–06
[11] Palomba V, Dino G, Ghirlando R, Micallef C and Frazzica A 2019 Decarbonising the Shipping Sector: A Critical Analysis on the Application of Waste Heat for Refrigeration in Fishing Vessels Appl. Sci. **9** 5143
[12] Xu X, Li Y, Yang S and Chen G 2017 A review of fishing vessel refrigeration systems driven by exhaust heat from engines *Appl. Energy* **203** 657–676
[13] Haikova T, Puzyr R. and Levchenko R. 2020 Experimental Studies on the Stress-Strain State under Drawing Aluminum–Copper Bimetal Parts Rectangular in Plan. *Russian Journal of Non-Ferrous Metals*, **61** (4) 404–412
[14] Prafulla D, Kozminski M, Peterson J and Kumar S 2019 Fouling Diagnosis of Pennsylvania Grade Crude Blended with Opportunity Crude Oils in a Refinery Crude Unit's Hot Heat Exchanger Train *Industrial & Engineering Chemistry Research* 17918–927
[15] Tynchenko V S, Petrovsky E A, Bukhtoyarov V V, Bashmur K A, Tynchenko V V and Kukartsev V V 2019 *Similarity criteria for modeling the process of pipes pulse pressing into the tube sheet* (J. Phys.: Conf. Ser)
[16] Omar S AL -Abri and Pervez T 2013 Structural Behavior of Solid Expandable Tubular Undergoes Radial Expansion Process- Analytical, Numerical, And Experimental *Approaches International Journal Solids and Structures* **50** 2980- 94
[17] Puzyr R, Savelov D, Shchetynin V, Levchenko R, Haikova T, Kravchenko S, Yasko S, Argat R, Sira Y and Shchipkovakyi Y 2018 Development of a method to determine deformations in the manufacture of a vehicle wheel rim *Eastern-European Journal of Enterprise Technologies* **4** 55–60
[18] Sosenushkin E, Yanovskaya A, Sosenushkin A and Emel'yanov V 2015 Mechanics of nonmonotonic plastic deformation *Russian Engineering Research* **35** 902–06
[19] Yang C, Li P and Fan L 2014 Blank Shape Design for Sheet Metal Forming based on Geometrical Resemblance *Procedia Engineering* **81**1487–92
[20] Wang X, Ouyang K and Xia J 2009 FEM analysis of drawing-thickening technology in stamping-forging hybrid process *Forging & Stamping Technology* **34** 73–78
[21] Houliara S and Karamanos S 2010 Stability of long transversely-isotropic elastic cylindrical shells under bending *International Journal of Solids and Structures* **47** 10–24
[22] Puzyr R, Savelov D, Argat R and Chernish A 2015 Distribution analysis of stresses across the stretching edge of die body and bending radius of deforming roll during profiling and drawing of cylindrical workpiece *Metallurgical and Mining Industry* **1** 27–32
[23] Kukhar V, Kurpe O, Klimov E, Balalayeva E and Dragobetskii V 2018 Improvement of the method for calculating the metal temperature loss on a Coilbox unit at the rolling on hot strip mills *International Journal of Engineering and Technology* **7** 35–39

[24] Fung-Huei Yeh 2007 Study of tube flaring forming limit in the tube flaring process *The Journal of Strain Analysis for Engineering Design* **42** 315-324
[25] Puzyr R, Kukhar V, Maslov A and Shchipkovskyi Y 2018 The Development of the Method for the Calculation of the Shaping Force in the Production of Vehicle Wheel Rims *International Journal of Engineering and Technology* **7** 30–34
[26] Razooqi A 2018 Experimental and Numerical Analysis of Expanded Pipe using Rigid Conical Shape *Journal of Engineering* **24** 106-119
[27] Omar S, AL -Abri and Pervez T 2013 Structural Behavior of Solid Expandable Tubular Undergoes Radial Expansion Process- Analytical, Numerical, And Experimental Approaches *International Journal Solids and Structures* **50** 2980-94
[28] Puzyr R, Haikova T, Majerník J, Karkova M and Kmec J 2018 Experimental Study of the Process of Radial Rotation Profiling of Wheel Rims Resulting in Formation and Technological Flattening of the Corrugations Manufacturing Technology **18** 106–111
[29] Karrecha A and Seibi A 2010 Analytical model for the expansion of tubes under tension *Journal of Materials Processing Technology* **210** 356–362
[30] Yeh F 2007 Study of flaring forming limit in the tube flaring process *Journal of Strain Analysis* **42** 315–342
[31] Patent of Polska WO 2006/135266. M. Burda, Z. Sova, K. Drzal, A. Masiolek. Method and apparatus for shaping various cross-sections on metal pipes
[32] Kalyughniyi V, Zaporozchenko A and Pimanov V 2012 Intensification of technologies of making of good is «Bulb 180x184» *Treatment of materials pressure: collection of scientific labour* **2** 136–140
[33] Puzyr R, Haikova T, Trotsko O and Argat R 2016 Determining experimentally the stress-strained state in the radial rotary method of obtaining wheels rims *Eastern-European Journal of Enterprise Technologies* **4** 52–60
[34] Geselbracht, Margaret J, Ellis Arthur B, Penn Rona L, Lisensky George C, Stone and Donald 1994 Mechanical Properties of Metals: Experiments with Steel, Copper, Tin, Zinc, and Soap Bubbles *J. Chem. Educ* **71** 254
[35] Markov O, Gerasimenko O, Khvashchynskyi A, Zhytnikov R and Puzyr R 2019 Modeling the techological process of pipe forging without a mandrel *Eastern-European Journal of Enterprise Technologies* **3** 42-48
[36] Popov E 1977 *Fundamentals of the theory of sheet stamping* (Mechanical engineering, Moscow)
[37] Fischer F D, Rammerstorfer F G and Daxner T 2006 *Flaring-an analytical approach International Journal of Mechanical Sciences* **48** 1246–55
[38] Maslov A, Batsaikhan J, Puzyr R and Salenko Y 2018 The determination of the parameters of a vibration machinef the internal compaction of concrete mixtures *International Journal of Engineering & Technology* **7** 12-19
[39] Savelov D, Dragobetsky V, Puzyr R and Markevych A 2015 Peculiarities of vibrational press dynamics with hard-elastic restraints in the working regime of metal powders molding *Metallurgical and Mining Industry* **2** 67–74
[40] Haikova T, Puzyr R, Dragobetsky V, Symonova A and Vakylenko R 2019 *Finite-Element Model of Bimetal Billet Strain Obtaining Box-Shaped Parts by Means of Drawin (DSMIE 2019, LNME*) ed V Ivanov et al (Lutsk, Ukraine: Springer) pp 85 – 94
[41] Salenko Y, Puzyr R, Shevchenko O, Kulynych V and Pedun O 2020 *Numerical Simulation of Local Plastic Deformations of a Cylindrical Workpiece of a Steel Wheel Rim (DSMIE 2020, LNME*) ed V Ivanov et al (Kharkiv, Ukraine: Springer) pp 442 – 451