The Assessment of the Process of Drawing a Cylindrical Workpiece Without Pressing with Alternating Strain of the Workpiece Flange

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The assessment of the process of drawing a cylindrical workpiece without pressing with alternating strain of the workpiece flange

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Abstract. The development of a method for drawing cylindrical parts without pressing the workpiece flange, which allows reducing the cost of production due to the use of dies without a fit ring and single-acting presses. The performed research revealed that this method results in obtaining cylindrical parts with drawing ratios typical for pressing drawing. In this case, the different thickness of the finished product is several times less compared with the same type of semi-finished products obtained by drawing with a fit ring. Steel, aluminum and copper workpieces were researched. The best results were shown by more plastic materials. This method is not applicable for materials with the less than 0.25 mm thickness.

Introduction

The method of manufacturing cylindrical parts by drawing in the cold state is used at almost all mechanical engineering enterprises, which include forging and workpiece-preparation workshops and sections. In large-scale production, rather productive drawing methods are mainly used, such as drawing with pressing the flange, with pulling ribs and sills, drawing on sheet stamping machines, drawing out from a tape, drawing out with thinning the wall, etc. [1-3]. In the medium and small batch production, the above methods are used. Other methods include stamping with elastic media, liquid and gas, soft metals, explosion stamping, package drawing, pulsating drawing, stamping with a profile tool, drawing with heating and local cooling, drawing on sheet punching hammers and hydraulic presses, drawing on hydraulic presses, rotary drawing, stamping with workpiece end support, non-pressing drawing [4-6]. In single and small-scale production, the use of most of the above methods is impractical due to the high costs and the duration of the die tooling manufacture, the use of multi-operation, which makes it difficult or almost impossible to switch to the production and development of products new types. The decisive role here will be played by partially universal or universal equipment, which can be used at any stage of manufacturing a new product [7-9].

From this point of view, the application of the non-pressing method in single and small-scale production is promising and low cost, since there is no need to complicate the equipment by the fit ring and use double- and triple-action presses. Therefore, the purpose of the work consists in the experimental research of the possibilities of the drawing method with alternating strain of the flange and the development of recommendations for production.

Material and methods

Drawing without a fold holder for flangeless parts is only possible with a low drawing coefficient $m = d/D \geq 0.75 \div 0.85$ [10, 11]. To implement this process, simple equipment is used, where the stamped part is mainly pulled to dip. It is difficult to turn a flat part into a hollow one. The process is accompanied by the formation of an insignificant amount of folds and their smoothing when pulling the cup through the gap between the die and the punch. Moreover, parts made of plastic metals and alloys with a large flange can be drawn without noticeable signs of corrugation without pressing only to a shallow depth of $h \approx (3 \div 6)\, s$. High values of h correspond to workpieces with big thickness. Drawing without pressing parts with big flange is only possible before the start of decreasing the size of the initial workpiece [5, 13, 14].

To test the possibility of obtaining high-quality cylindrical parts by drawing without pressing the flange, experimental research was carried out on round workpieces of various diameters and thicknesses. The workpieces dimensions exceeded the ultimate ones, but they were corrected according to the L.I. Shofman condition of the stability loss [11, 17]. Workpieces made of 08 kp steel, aluminum A2 and copper M4 were subjected to drawing without pressing. The diameters of workpieces made of 08 kp steel were 77, 80, 83 mm, thickness – 1.2 mm, punch diameter – 46.8 mm. For

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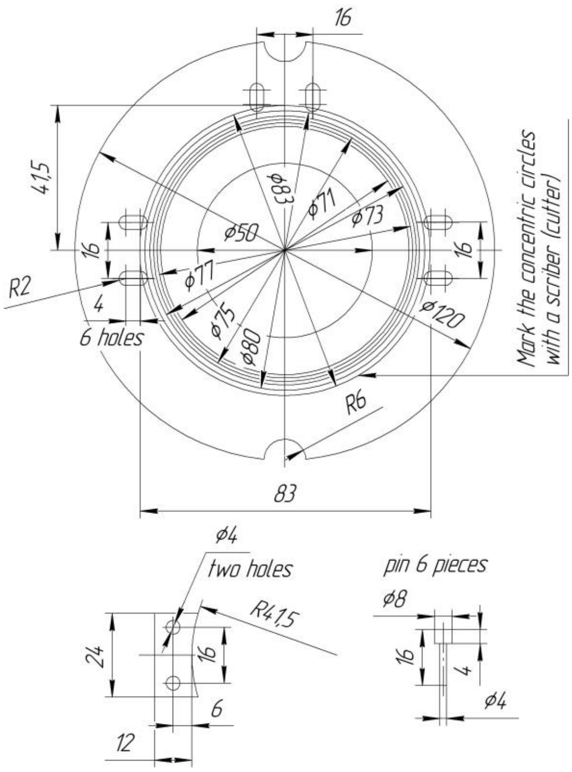
aluminum the diameters of the workpieces were 83, 86, 89 mm, thickness – 1.4 mm, the punch diameter – 46.4 mm. For copper – 58, 61, 64 mm, workpiece thickness – 0.25 mm, the punch diameter – 49 mm. For all sizes of workpieces, the diameter of the inlet of the die was 50 mm. The radius of curvature of the die for all experiments was chosen the same and equal to 5 mm, the radius of curvature of the punch for all experiments was 4 mm.

The process of drawing without a fold holder is accompanied by the difficulty of centering the workpiece on the die and, as a result, unilateral tightening of the semi-finished product, the appearance of premature folds and destruction at the location of strains, and these processes are aggravated when using the same die for workpieces of different diameters.

a)



b)

Fig. 1. A die with centering elements: a – a photo of the die; b – a detailed outline of the matrix.

Therefore, to conduct these experiments, a universal die with movable centering elements was designed, with the help of which the workpiece was accurately aligned with the hole of the die and punch. Here, the clamps move along the radial grooves simultaneously and synchronously with each other to the center or from the center of the die, which ensures self-centering of the workpieces (Fig. 1). The ultimate diameters for drawing is performed without fold formation are: for steel – D = 76 mm, for copper – D = 56 mm, for aluminum – D = 80 mm [15-17].

Calculation

At the first stage of drawing the punch stroke was limited according to the leap in effort at the stroke-effort diagram of the tensile machine. So the corrugations formed on the flange prevent the workpiece from being pulled into the die hole. It was noted that for different thicknesses of the workpieces, the value of the stroke of the punch, at which the leap in effort was observed, was also unequal. An empirical dependence was proposed for calculating the length of the penetration of the punch into the workpiece. It accurately described this process component

$$l = r_d + r_p + s/2, \tag{1}$$

where s – the workpiece thickness; r_d – the radius of the die rounding; r_p – the radius of the punch rounding.

After the first stage of drawing passed, the semi-finished product with corrugations was removed from the die, turned by 180° and reinstalled. It was centered with the use of moving elements. The stroke of the punch was turned on and the semi-finished product was deformed until the corrugations on the flange were smoothed out. Then the punch was stopped and it was given a precisely calculated stroke until a new formation of folds of the inverse curvature on the flange. The length of the reverse stroke of the punch was calculated by mathematical dependence

$$l_2 = l_1 + \Delta h, \tag{2}$$

where l_1 – the length of the punch stroke at the first step; Δh – the addition to the reverse stroke calculated by the G. Backhaus model taking into account the Bauschinger effect [14, 18-20, 22-25].

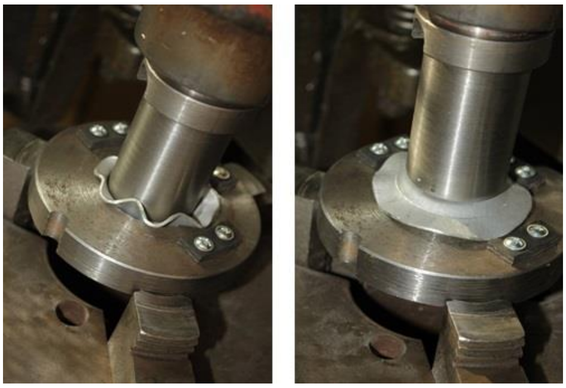
Then the semi-finished product was removed from the die, turned over by 180º and the process was repeated until the desired product height was obtained. Thus, all batches of workpieces were drawn, and their final height exceeded the standard height of the products obtained by drawing without pressing the flange and corresponded to the height of the drawn parts with the use of pressing. So, e.g. the drawing coefficient for the aluminum part with the workpiece diameter D = 80 mm was m = d/D = 0.58, the workpiece height – h = 24.5 mm (according to the tables of Romanovskyi V.P. [17, 21, 26-28]). It is recommended to perform this drawing with pressing, cutting allowance – about *3.5* mm according to the data of Skvortsov G.D. [17, 29, 31]. I.e. the final height of the finished part is 21 mm. It is impossible to obtain such a part by drawing without pressing the flange.

Results

However, the experiment result revealed that the use of drawing with step-by-step stretching of the workpiece flange makes it possible to produce parts of sufficient quality with this ratio of the dimensions. Figs 2, 3 demonstrate drawing steps with the workpiece turning and Fig. 4 – the semi-finished products and the finished part.

a) b) c)

Fig. 2. The workpiece drawing without a fold holder (material – 08 kp steel, the workpiece diameter – 77 mm): a – the punch approach to the workpiece; b –the formation of folds at the direct stroke of the punch; c – smoothing out the folds at the reverse stroke of the punch.



a) b)

Fig. 3. Drawing with turning the workpiece (material – A2 aluminum; the workpiece diameter – D = 86 mm): a – the direct stroke of the punch (the 4-th turning of the workpiece); b – the reverse stroke of the punch (the 5-th turning of the workpiece).

When conducting experiments on drawing workpieces without pressing the flange, the thicknesses of the obtained parts were also measured [30, 34, 35]. To do this, we used a micrometer thickness gauge with a measuring range of 0–25 mm and a division value of 0.01 mm to determine the strain mechanism and to formulate recommendations on the application of this process to production. The question of the legitimacy of determining the additional stroke of the punch by theoretical dependences based on the Bauschinger effect [32, 33] and recommended for use in this drawing method also remained open. Some results of the performed experimental research are presented in Table 1, which shows the dimensions of the workpieces and the drawn parts, their thickness in the characteristic zones of the profile, the material, the number of turnings to obtain the given height, the variants of the loss of stability and destruction, as well as the size of the first stroke of the punch and the addition at the reverse of the stroke load.

a)

b)

c)

Fig. 4. Semi-finished products and the completed part obtained by the method of step-by-step stretching of the flange (material – A2 aluminum, the workpiece diameter – 86 mm, m = d/D = 0.58, the thickness – 1.4 mm, the punch diameter – 46.4 mm, the height of the part after cutting the flange – 22 mm, the number of turnings – 8): a – the semi-finished product after the first step; b – the

semi-finished product after the fourth load reverse; c – the completed part after cutting the flange.

Table 1. The results of experiments on the drawing with a step-by-step stretching of the flange.

The material of the workpiece	**M4 copper**		
D, mm	58	61	64
m = d/D	0.86	0.82	0.78
Workpiece height / Number of turnings mm/ps	4.2/4	–	–
The first stroke of the punch / Addition at the reverse, mm	1.2/0.5	–	–
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.99; 0.96; 0.98; 0.89; 0.88	–	–
Notes	high-quality	folds at the end loss of bottom stability	
The material of the workpiece	**08 kp steel**		
D, mm	77	80	83
m = d/D	0.65	0.625	0.60
Workpiece height / Number of turnings mm/ps	16.2/6	17.5/6	19.8/8
The first stroke of the punch / Addition at the reverse, mm	5.5/2	5.5/2	5.6/2
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.94; 0.84; 0.89; 0.83; 0.81	0.92; 0.79; 0.86; 0.79; 0.79	0.92; 0.79; 0.84; 0.77; 0.76
Notes	high-quality	high-quality	high-quality
The material of the workpiece	**A2 aluminum**		
D, mm	83	86	89
m = d/D	0.60	0.58	0.56
Workpiece height / Number of turnings mm/ps	20.1/6	22.1/8	24.4/8
The first stroke of the punch / Addition at the reverse, mm	6.5/2.5	6.5/2.5	6.5/2.5
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.92; 0.8; 0.86; 0.79; 0.77	0.94; 0.77; 0.84; 0.77; 0.76	0.93; 0.77; 0.86; 0.76; 0.75
Notes	high-quality	high-quality	high-quality

However, it was noted that this process does not go smoothly and there are difficulties and shortcomings in the size of the stroke of the punch, as well as alignment of the workpiece after turning, which results in its destruction in the form of the separation of the bottom (Fig. 5).

Fig. 5. Pulling down of the workpiece part and it's destruction in the form of the separation of the bottom.

These phenomena's leaded to an increase in the number of rejected parts and the instability of the drawing process, which is unacceptable in the current production. Therefore, during the course of this experiment, some improvements in the die design were made and the methodology for calculating the additional stroke of the punch was improved taking into account the results of the experimental research.

Discussion

The table demonstrates that it is possible to obtain the aluminum and steel parts after at least six turnings. The number of turnings depends on the workpiece diameter and the drawing coefficient. With the larger diameter and the smaller the drawing coefficient, the greater number of the turnings is necessary to obtain a normal part. Aluminum is a more ductile metal in this case; in comparison with steel it requires a smaller number of steps with the same initial parameters and drawing coefficient. However, the thickness of the workpiece is higher for aluminum than for steel, which may explain the better stability of the workpiece flange and the possibility to obtain increased strains during one step. Drawing of thin metals by this method is difficult, because when the workpiece approaches the shape of the finished part, the corrugations are not completely smoothed out and remain on the product, which is unacceptable. Besides, the turning of thin workpieces and their strain results in a loss of bottom stability in the form of local buckling of metal. It is shown in the table for copper workpieces whose thickness is 0.25 mm.

The results of the measurements of the thicknesses of the characteristic zones of the semi-finished product allow us to conclude that the nature of the strain of the workpiece by this method is radically different from the method of the strain by drawing with a fit ring. The data in column 6 shows that the workpiece deforms along its entire perimeter. This is not characteristic of the classical drawing method, where the bottom of the part is practically not deformed, and mainly the workpiece flange is subjected to plastic strains [36, 39]. When turning, during shaping, the zone of transition of the wall to the bottom of the part and the workpiece flange are subjected to the greatest strains. Moreover, the main difference is the thinning of the flange, and not it's thickening as in the classic drawing. Plastic strain covers all zones of the workpiece and the end face of the workpiece receives compressive deformations in thickness, which indicates the large tensile stresses acting here, comparable with their value at the transition of the wall to the bottom. Based on the experimental data, the ratio of thicknesses in these zones is practically of the same order: steel – 0.83/0.81; 0.79/0.79; 0.77/0.76; aluminum – 0.79/0.77; 0.77/0.76; 0.76/0.75. However, the experimental result revealed that the use of drawing with step-by-step stretching of the workpiece.

Conclusions

Thus, the conducted experiments confirmed the possibility of manufacturing cylindrical parts by drawing without pressing the workpiece flange with its step-by-step stretching. It will allow applying the method to a single and small batch production using simple presses and mold tools without a fold holder. However, one question remains open. It is the problem of the maximum diameter of the workpiece for this method, more precisely, the ratio of the diameter of the workpiece to the diameter of the part. Also the possibilities of stamping workpieces that are outside the range of sizes given in this research have not been analyzed.

References

1. L.M. Gurevich, V.M. Volchkov, Yu.P. Trykov, O.S. Kiselev, *Modeling the process of deep drawing of tubular adapters made of titanium-aluminum laminated plates.* Transactions of universities. Nonferrous metallurgy, **4**, 30 (2014)
2. T. Haikova, R. Puzyr, V. Dragobetsky, A. Symonova, R. Vakylenko, *Finite-Element Model of Bimetal Billet Strain Obtaining Box-Shaped Parts by Means of Drawing.* In: Ivanov V. et al. (eds) Advances in Design, Simulation and Manufacturing II, Proceedings of the 2nd International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE-2019, 85 (2019)
3. J.C. Luo, *Study on Stamping-Forging Process and Experiment of Sheet Metal Parts with Non-uniform Thickness.* Wuhan: Huazhong University of Science & Technology, **51**, 49 (2011)
4. M.A. Hassan, K.I.E. Ahmed, N. Takakura, *A developed process for deep drawing of metal foil square cups.* Journal of Materials Processing Technology, **212(1)**, 295 (2012)
5. X.Y. Wang, K. Ouyang, J.C. Xia, *FEM analysis of drawing-thickening technology in stamping-forging hybrid process.* Forging & Stamping Technology, **34(4)**, 73 (2009)
6. M. Gavas, M. Izciler, *Effect of blank holder gap on deep drawing of square cups.* Materials and Design, **28**, 1641 (2007)
7. O.V. Kalyuzhnyi, V.L. Kalyuzhnyi, *Intensification of forming processes of cold sheet stamping* (Kyiv, Sik Group Ukraine LLC, Ukraine, 2015)
8. G.X. Yan, X.Y. Wang, L. Deng, *A study of hole flanging-upsetting process.* Advanced Materials Research, **939**, 291 (2014)
9. J.C. Luo, *Study on Stamping-Forging Process and Experiment of Sheet Metal Parts with Non-uniform Thickness.* Wuhan: Huazhong University of Science & Technology, **51**, 49 (2011)
10. R. Puzyr, D. Savelov, R. Argat, A. Chernish, *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, Ukraine, **1**, 27 (2015)
11. E.A. Popov, *Fundamentals of the theory of sheet punching* (Moscow, engineering, 1977)
12. A. Maslov, J. Batsaikhan, R. Puzyr, Y. Salenko, *The determination of the parameters of a vibration machine the internal compaction of concrete mixtures*. International Journal of Engineering & Technology, **7(4.3)**, 12 (2018)
13. Y. Salenko, R. Puzyr, O. Shevchenko, V. Kulynych, O. Pedun, *Numerical Simulation of Local Plastic Deformations of a Cylindrical Workpiece of a Steel Wheel Rim*. In: Ivanov V. et al. (eds) Advances in Design, Simulation and Manufacturing III, Lecture Notes in Mechanical Engineering, DSMIE 2020, 442 (2020)
14. A. Khosravifard, R. Ebrahimi, *Investigation of parameters affecting interface strength in Al/Cu clad bimetal rod extrusion process.* Materials and Design, **31**, 493 (2010)
15. S. Kapifiski, *Analytical and experimental analysis of deep drawing process for bimetal elements.* Journal of Materials Processing Technology, **60**, 197 (1996)
16. V.P. Romanovskii, *Reference book on cold forging* (Leningrad, engineering, 1976)
17. S.A.A. Akbari-Mousavi, L.M. Barrett, S.T.S. Al-Hassani, *Explosive welding of metal plates*. Journal of Materials Processing Technology, **202(1-3)**, 224 (2008)
18. M.V. Zagirnyak, V.V. Drahobetskyi, *New methods of obtaining materials and structures for light armor protection.* Military Technologies (ICMT), International Conference, Brno, Czech Republic, **1**, 705 (2015)
19. V. Dragobetsky, V. Zagoryansky, A. Voronin, *Process modeling of elastic-plastic deformation of steel-aluminum compositions produced by impact bonding*. Metallurgical & Mining Industry, **9**, 1186 (2015)

20. D.I. Adeyemi, A. Bolaji, O.A. Mosobalaje, J.O. Oluyemi, D.S. Moshood, *Effect of Heat Treatment on Some Mechanical Properties of 7075 Aluminium Alloy*. Materials Research, **16(1)**, 190 (2013)
21. W.H.A. Shwe, T.L. Kay, K.K.O. Waing Waing, *The effect of ageing treatment of aluminum alloys for fuselage structure-light aircraft*. World Academy of Science, Engineering and Technology, **46**, 696 (2008)
22. T. Mohammad, E. Esmaeil, *Mechanical and anisotropic behaviors of 7075 aluminum alloy sheets*. Materials and Design, **32(2)**, 1594 (2010)
23. J.F. Li, Z.W. Peng, C.X. Li, Z.Q. JIA, W.J. Chen, Z.Q. Zheng, *Mechanical properties, corrosion behaviors and microstructures of 7075 aluminium alloy with various aging treatments.* Transactions of Nonferrous Metal Society of China, **18(4)**, 755 (2008)
24. B.F. Roberto, G.L. Terence, *Using severe plastic deformation for the processing of advanced engineering materials.* Materials Transactions, **50(7)**, 1613 (2009)
25. S. Miyazaki, S. Kumai, A. Sato, *Plastic deformation of Al–Cu–Fe quasicrystals embedded in Al2Cu at low temperatures.* Mater Sci Eng A, **300-5**, 400 (2005)
26. C.-Y. Chen, W.-S. Hwang, *Effect of Annealing on the Interfacial Structure of Aluminum-Copper Joints.* Materials Transactions, **48(7)**, 1938 (2007)
27. H. Mirzakouchakshirazi, A.R. Eivani, Sh. Kheirandish, *Effect of Post-Deformation Annealing Treatment on Interface Properties and Shear Bond Strength of Al-Cu Bimetallic Rods Produced by Equal Channel Angular Pressing.* Iranian Journal of Materials Science & Engineering, **14(4)**, 25 (2017)
28. R. Puzyr, D. Savelov, V. Shchetynin, R. Levchenko, T. Haikova, S. Kravchenko, S. Yasko, R. Argat, Y. Sira, Y. Shchipkovakyi, *Development of a method to determine deformations in the manufacture of a vehicle wheel rim.* Eastern-European Journal of Enterprise Technologies, **4, 1(94)**, 55 (2018)
29. R. Puzyr, T. Haikova, O. Trotsko, R. Argat, *Determining experimentally the stress-strained state in the radial rotary method of obtaining wheels rims.* Eastern-European Journal of Enterprise Technologies, **4, 1(82)**, 52 (2016)
30. A.V. Grushko, V.V. Kukhar, Y.O. Slobodyanyuk, *Phenomenological Model of Low-Carbon Steels Hardening during Multistage Drawing*. Solid State Phenomena, **265**, 114 (2017)
31. I. Hugo, P.J. Medellín-Castillo, D.F. García-Zugasti, F.J. de Lange, A. Colorado, *Analysis of the allowable deep drawing height of rectangular steel parts.* The International Journal of Advanced Manufacturing Technology, **66(1-4)**, 371 (2013)
32. W. Leyu, E. Daxin, *Numerical simulation analysis of variable BHF drawing of rectangular cup on curve blank-holder.* Mod Manuf Eng, **2**, 73 (2006)
33. V.A. Ogorodnikov, I.A. Derevenko, R.I. Sivak, *On the Influence of Curvature of the Trajectories of Deformation of a Volume of the Material by Pressing on Its Plasticity Under the Conditions of Complex Loading*. Materials Science, **54(3)**, 326 (2018)
34. I. Aliev, Y. Zhbankov, S. Martynov, Forging of shafts, discs and rings from blanks with inhomogeneous temperature field. Journal of Chemical Technology & Metallurgy, **51(4)**, 393 (2016)
35. Y. Chen, L. Peng, F. Lixia, *Blank shape design for sheet metal forming based on geometrical resemblance.* Procedia Engineering, **81**, 1487 (2014)
36. T. Haikova, R. Puzyr, D. Savelov, V. Dragobetsky, R. Argat, R. Sivak, *The Research of the Morphology and Mechanical Characteristics of Electric Bimetallic Contacts*. In: Chenchevoy, V. et al. (eds.) Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice, PAEP 2020, Ukraine, 579 (2020)
37. G. R. Semyon, *Statistical Methods for Experimental Data Processing. Evaluating Measurement Accuracy* (Springer, New York, NY, 2013)
38. R.H. Puzyr, V.T. Shchetynin, R.H. Arhat, Yu.B. Sira, V.V. Muravlov and S.I. Kravchenko, *Numerical modeling of pipe parts of agricultural machinery expansion by stepped punches.* IOP Conference Series: Materials Science and Engineering, **1018(1)**, 012013 (2021)