

# Study of technological factors' effects on deforming of thin-wall tubes deformation forces in short-term creep mode

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**Abstract.** In the modern world, slow isothermal deformation, which leads to a significant increase of the deformed metal's plasticity, have become more widely used in the manufacturing of ax-isymmetric products made of hard-to-deform light alloys. Despite a large number of works devoted to theoretical and experimental research of distribution processes, the problems of the forming theory have not been fully discussed at the present time. This paper presents the results of studies of the pipe workpiece expansion under isothermal conditions, performed in the QFORM 3D software. The workpiece was made of high-strength alloys AMg6 and BT6. It was assumed that the behavior of the workpiece material during deformation corresponds to the following equation, which characterizes the transition of the workpiece material from viscous to viscoplastic state. The study reveals the influence of a wide range of technological factors on the stress-strain state and operational force parameters. The results can be used to create scientifically based methodologies for the design of high technology processes for manufacturing of axisymmetric geometrically-complex parts using isothermal deformation methods.

## 1. Introduction

In the modern world, slow isothermal deformation, which leads to a significant increase of the deformed metal's plasticity, have become more widely used in the manufacturing of axisymmetric products from hard-to-deform light alloys. When developing the technology of isothermal expansion, it is necessary to take into account that the deformation values become extremely high, and, accordingly, the mechanical characteristics of the deformed materials change significantly. In connection with the foregoing, there is a need to apply the plasticity and creep theory to analyze isothermal forging and expansion in particular.

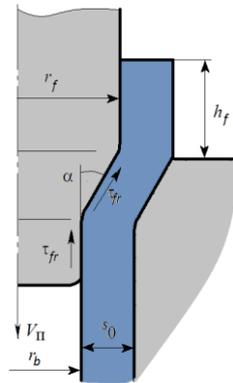
Despite a large number of works devoted to theoretical and experimental studies of crimping and expansion, the issues of the forming theory for anisotropic materials with cylindrical anisotropy of mechanical properties have not been practically discussed at present. A wide range of problem related to the design of technological processes of crimping and expansion of tube workpieces and the search for rational conditions for managing these processes, ensuring the manufacturing of products of specified quality, has not been resolved.

## 2. Materials and methods

The paper presents the results of studies of tube workpiece expansion under isothermal conditions, performed in the QFORM 3D software. A complex based on the finite element method was used due to the analysis of the data obtained in the course of theoretical studies based on the upper boundary



plasticity theorem and the results of experiments. The scheme of the process is shown in Fig. 1. The investigations were carried out with the following tool and equipment parameters: the radius of the conical sections' transformation into the cylindrical ones is 1 ... 7 mm; the taper angle of the tool is 10 ... 40 degrees; workpiece thickness: 1 ... 3 mm; friction coefficient: 0.1 ... 0.8; deformation rate: 0.01 ... 1 mm / s, expansion coefficient is 1 ... 1.5.



**Figure 1.** Expansion scheme

### 3. Results and Discussion

The workpiece was made of high-strength alloys AMg6 and BT6. Theoretical studies, carried out according to the model developed earlier, are based on the upper boundary plasticity theorem, the solution of which will be based on energy calculation methods [1-15]. It was assumed that the behavior of the workpiece material during deformation corresponds to the following equation, which characterizes the transition of the workpiece material from viscous to viscoplastic state

$$\sigma_e = A \varepsilon_e^m \xi_e^n, \quad (1)$$

where  $\sigma_e$ ,  $\varepsilon_e$ ,  $\xi_e$  - equivalent stress, strain and deformation rate;  $A$ ,  $m$ ,  $n$  - material properties. For our case, the following energy inequality is valid:

$$N_B \leq N_{BH}, \quad (2)$$

where  $N_B = qSV_n$ ;  $N_{in} = N_f + N_{fr}$ ;  $N_f = \int_{V_f} \sigma_e \xi_e dV_f$ ;  $N_{TP} = \int_{S_{fr}} \tau_{fr} V_k dS_{fr}$ .

In this inequality  $q$  is the forging pressure;  $\tau_{fr}$  is the stress arising from friction between the tool and the workpiece;  $V_n$  - speed of the working tool;  $V_k$  - workpiece speed;  $S$ ,  $S_{fr}$ ,  $W$  - the cross-sectional area of the tube workpiece, the area at the point of contact of the part and the tool, and the volume of the deformation zone.

The expansion pressure is expressed by the formula [1-3]

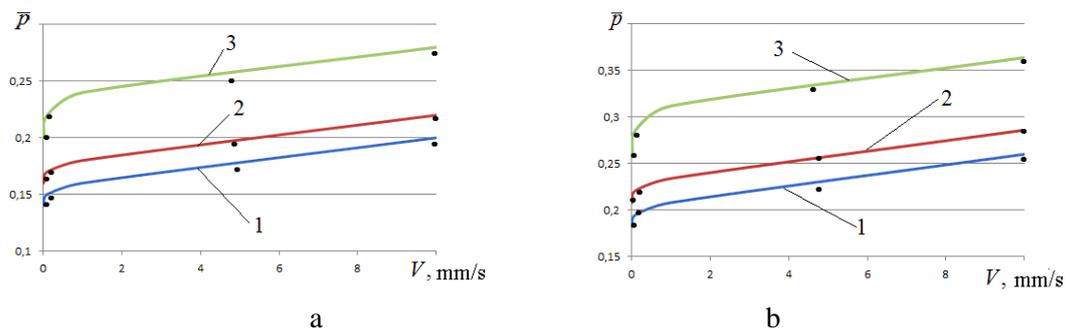
$$q \leq \frac{Ak^{m+n}}{2\sin\alpha} r_n^{\frac{R_z n - 1}{1 + R_z}} V_{II}^n \left( \sqrt{\frac{2(2 + R_z)}{3(1 + R_z)}} + \mu \tan\alpha \right) \int_{r_0}^{r_1} r^{1 - (1+n)\frac{1+2R_z}{1+R_z}} (\ln K_p)^m dr_T. \quad (3)$$

On the basis of the formulas presented earlier, the optimum shape and dimensions of the tool were revealed, providing the best quality properties of the produced parts and the minimum deformation force. The calculations were made with the following geometric dimensions of the workpieces:

$r_b = 10..20$  mm;  $r_f = 20..30$  mm;  $s_0 = 1..3$  mm;  $h_f = 5..10$  mm;  $\alpha = 15..45^\circ$ .

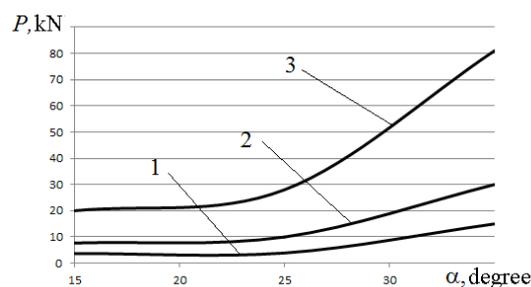
Figure 2 shows the graphical dependencies between the speed of the deforming tool and the relative pressure value of expansion with different friction values, which characterize the lubricants used in the

production. Their analysis shows that the most significant effect on the distribution force has the change in the punch speed in the interval from 0.01 to 0.1 mm/s. Then the pressure increases, but not so intensively. The increase of the friction coefficient gives a uniform and linear increase in pressure during the expansion, i.e. with the increase of friction from 0.1 to 0.4, the pressure increases by 1.5. The results of the studies, based on mathematical and computer modeling, and on the experimental data were compared. According to the results it can be seen that the results obtained in the computer modeling have a small difference (no more than 10%) from the results obtained in the course of mathematical modeling and experiments and qualitatively repeat the patterns of influence of various factors on force. This allows us to carry out more complete studies of this process, depending on a greater number of factors, using computer modeling.



**Figure 2.** Dependence of change in  $\bar{p}$  from  $V$  during expansion of alloys AMg6 (a) and BT6C (b): 1 -  $\mu = 0,1$ ; 2 -  $\mu = 0,2$ ; 3 -  $\mu = 0,4$

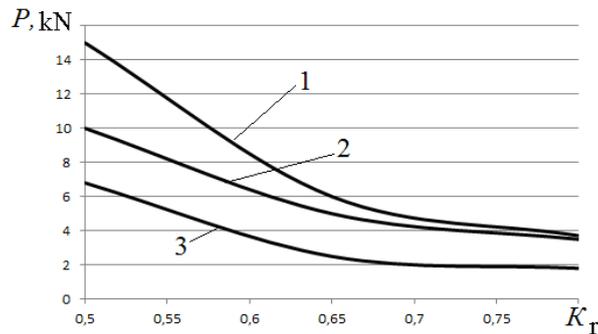
Figure 3 shows the dependence of the isothermal expansion force on the taper angle of the tool and friction on the tool and workpiece.



**Figure 3.** Dependence of the expansion force on the taper angle of the tool: 1 -  $\mu = 0,1$ ; 2 -  $\mu = 0,4$ ; 3 -  $\mu = 0,8$

This dependence demonstrates that with increasing tool taper angle and friction the distribution force is also increasing. The greatest growth of strength occurs after increasing the taper angle of the tool higher than 25 degrees. The increase in the friction coefficient linearly affects the growth of the distribution force. Analysis of this dependence makes it possible to establish rational parameters of friction and the geometry of the expansion tool, i.e. the angle at a single transition should not exceed 30 degrees when friction is the lowest.

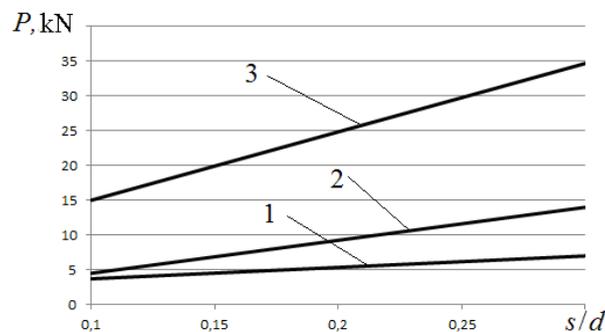
Figure 4 shows the dependence of isothermal expansion force from the isothermal expansion coefficient and the radius of tool curvature for the zones of transition from the cylindrical into tapered sections.



**Figure 4.** The dependence of the force from the expansion coefficient: 1 -  $R = 1$  mm; 2 -  $R = 3$  mm; 3 -  $R = 7$  mm

This dependence demonstrates that with the increase in the expansion coefficient and the tool curvature radius, the expansion force decreases. The greatest, more than double, increase in strength occurs at the value of the expansion ratio of 0.65 and below. The increase in the radius of the transition zone from cylindrical to tapered sections does not affect the force value so intensively, but at radii less than 3 mm there is a noticeable increase in the force value. Thus, when the expansion coefficient equals 0.8, the growth of cylindrical-tapered transition radius from 1 mm to 3 mm leads only reduction force by 15%, while at the same time when the expansion coefficient is 0.5, the same growth radius reduces the force by 60%.

Figure 5 shows the dependence of isothermal expansion force from the relative thickness of the workpiece and the taper angle of the tool.



**Figure 5.** The dependence of the expansion force from the relative thickness of the workpiece: 1 -  $\alpha = 15^\circ$ ; 2 -  $\alpha = 25^\circ$ ; 3 -  $\alpha = 35^\circ$

This dependence demonstrates that with the increase of tool's taper angle and relative thickness of the workpiece, the expansion force increases. It should be noted that the increase in the thickness of the workpiece in parallel with the increase of the taper angle of the punch leads to a more and more intensive increase in the force, that is, with simultaneous increase in both the thickness and the angle of expansion. With the given parameters of the taper angle growth of more than 25 degrees, the force increases by more than three times.

#### 4. Conclusion

This paper presents the research of expansion of tube ends made of high-strength materials in the short-term creep mode. Experiments on the expansion and upsetting of the tube workpiece end under isothermal conditions were carried out using the QFORM 3d software. The results reveal the influence

of a wide range of technological factors on the stress-deformation state and the force parameters of the operations under research.

By analyzing and generalizing the obtained theoretical results, we formulated the recommendations for the design of manufacturing technology for "adapter" parts. The results can be used to create scientifically valid, innovative, high-tech and competitive processes of the next generation for manufacturing of axisymmetric geometrically-complex parts by means of isothermal deformation.

## 5. Acknowledgments

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## References

- [1] Unksov E P Theory of plastic deformations of metals 1983 *M. : Mechanical Engineering* 598.
- [2] Romanov K I Mechanics of hot metal forming 1993 *Moscow: Mashinostroenie* 240.
- [3] Springer P, Prahl U Characterisation of mechanical behavior of 18CrNiMo7-6 steel with and without nb under warm forging conditions through processing maps analysis 2016 *Journal of Materials Processing Technology* **Volume 237** 216-234
- [4] Netoa D M, Martins M P, Cunha M, Alves L M, Oliveira C, Laurent H, Menezes L F Thermo-mechanical finite element analysis of the AA5086 alloy under warm forming conditions 2017 *International Journal of Solids and Structures Available online*.
- [5] Zhengyang Cai, Min Wan, Zhigang Liu, Xiangdong Wu, Bolin Ma, Cheng Cheng Thermal-mechanical behaviors of dual-phase steel sheet under warm-forming conditions 2017 *International Journal of Mechanical Sciences* **Volume 126** 79-94.
- [6] Verena Kräusel, Peter Birnbaum, Andreas Kunke, Rafael Wertheim Metastable material conditions for forming of sheet metal parts combined with thermomechanical treatment 2016 *CIRP Annals - Manufacturing Technology* **Volume 65 Issue 1** 301-304.
- [7] Aksenov S A, Chumachenko E N, Kolesnikov A V, Osipov S A Determination of optimal gas forming conditions from free bulging tests at constant pressure 2015 *Journal of Materials Processing Technology* **Volume 217** 158-164.
- [8] Kyung-Hun Leea, Byung-Min Kim Advanced feasible forming condition for reducing ring spreads in radial–axial ring rolling 2013 *International Journal of Mechanical Sciences* **Volume 76**, 21-32.
- [9] Malinin N N Creep in metal processing 1986 *M. : Mechanical Engineering* 216.
- [10] Yakovlev S S, Yakovlev S P, Chudin V N, Tregubov V I, Chernyaev A V Isothermal shaping of anisotropic materials by a rigid tool in the regime of short - term creep 2009 *M. : Mechanical Engineering* 412.