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THE TECHNOLOGY OF TUBE HYDROFORMING AND PARAMETERS PROCESS

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Abstract: The tube plastic deformation technology represent metal forming technology that involves flexible production process that can be realized through various technological solutions and the tool design itself. Each additional requirement to fulfill some special requirements, in terms of tube shape and geometry, almost always implies non-standard technologies that significantly price increase of the finished product. For these reasons, the application of incompressible fluid in these processes, with certain limitations, can greatly improve and fulfill the requirements that are placed before the finished product. The paper presents a geometric tool model, with a preliminary analysis of the mechanical parameters of the design process, with the possibility of designing the technology itself.
Keywords: hydroforming, stress, strain, tool, pressure

INTRODUCTION

The proposed technology of supplying compensating tubes first of all requires a detailed analysis of the parameters of the tube manufacturing process, because it is a complex metal forming process of plastic deformation where the desired tube profile is obtained by means of an incompressible fluid [1].

For these reasons, the required pressure of the fluid inside the tube, or the entire installed hydraulic unit, is to be analyzed, which should allow the working pressure of the fluid [2]. It starts from the Laplacian equation for the deformation of the sheet according to the instantaneous without moment theory and the geometric conditions that are set by the tool geometry itself to get pressure inside the pipe. In order to make deformation possible at all, the axial compression force of the tube in the tool is also provided to allow plastic deformation against the removable and moving tools walls [3,4]. Such a detailed analysis was used for construction and tool design for the mentioned technology which, based on 3D models and complete technological documentation, were realized to the exploitation conditions of the production itself.

MECHANICAL PARAMETERS DEFINE

The most important task in analyzing the design of the tubular compensator by the hydraulic design method is the correct determination of the value of the required pressure of the fluid in the tube itself during the design process [2].

Based on the pressure value obtained, the calculation of the most important construction and structural elements of the tool sets and the selection of materials for individual parts of the tool is carried out. The required pressure can be determined from Laplace's equation

$$\frac{\sigma_\rho}{R_\rho}+\frac{\sigma_\theta}{R_\theta}=\frac{p}{s} \qquad (1)$$

where is: $R_\theta=\frac{\rho}{\cos\alpha_i}$, R_r – radius of curve in the tangential and meridian direction respectively,

Solving Laplace's equation by an unknown size of internal pressure p is obtained:

$$p=\frac{s}{R_\rho}\sigma_\rho+\frac{s}{R_\theta}\sigma_\theta \qquad (2)$$

If the expressions for radial and tangential stress σ_ρ and σ_θ are entered in the above expression, a general expression for determining the pressure in the form is obtained:

$$p=\frac{s\cdot\beta K\left(\frac{1-\frac{R_0}{\rho}}{R_\rho}+\frac{1}{R_\theta}\right)-\frac{s}{R_\rho}\frac{R_0}{\rho}\frac{F_a}{A}}{1+\frac{s}{R_\rho}\left(1+\frac{R_0}{\rho}\right)+\frac{s}{R_\theta}} \qquad (3)$$

Instead of the variable radius R_ρ and R_θ, the variable can be included in the obtained expression α_i , if the radius are replaced by the terms given in the deformation state analysis. From the general expression (3) it can be seen that the pressure is higher if the thickness of the tube wall is larger and the tube diameter is smaller [2]. By increasing the axial compression force, the required pressure decreases. When the coordinate ρ is increased, i.e. the height of the ribs, the necessary pressure is growing. Based on the above, it follows that the internal pressure in the tube is variable value and changes during the metal forming process. However, it is much conviniant process to metal forming with constant pressure, in which case the axial compression force is variable during the time of metal forming [5]. The value of the required pressure is determined from the condition that the internal pressure is the same at any time in the metal forming process, even at the beginning. If the initial conditions are:

$$\rho = R_0 \qquad R_\rho = \infty \qquad R_\theta = \frac{\rho}{\cos 0} = R_0 \qquad K = K_0$$

by replacement into expression (3) gives a simplified expression for determining the required pressure in the form:

$$p = \frac{s \cdot \beta \cdot K}{R_0 + s} \tag{4}$$

which indicates that the internal pressure depends only on the type of tube material and the dimensions of the tube. As the thickness of the tube wall increases, the pressure increases, and with the increase in the tube diameter it decreases [6].

Unless the curves of hardening for the given material are available, one of the empirical aproximation can be used to evaluate the actual curve of hardening. In this case, the most commonly used is the linear approximation according to the expression:

$$K = K_0 + \Pi \cdot \varphi_i \tag{5a}$$

and exponential aproximation curve:

$$K = C \cdot \varphi_i^n \tag{5b}$$

In previous expresion labels K_0, n, C, Π represent constants that depend on the type of material, while with φ_i the intensity of the deformation is determined by the expression:

$$\varphi_i = \frac{\sqrt{2}}{3}\sqrt{(\varphi_\rho - \varphi_\theta)^2 + (\varphi_\theta - \varphi_n)^2 + (\varphi_n - \varphi_\rho)^2} \tag{6}$$

and in the conditions of the axe symetric deformation state:

$$\varphi_i = \frac{\sqrt{2}}{3} \cdot 2\varphi_\theta \approx \varphi_\theta \tag{7}$$

The results of the theoretical analysis presented in this paper were obtained according to the expressions (5b) and (6) where the values of the true stress were obtained from the empirical expression for stainless steel:

$$K = K_0 + 3{,}2(100 \cdot \varphi_i)^{0{,}84} \tag{9}$$

where is: $K_0 = \sigma_v$ - stress at the yield point. When carrying out metal forming experiments in this investigation process was done with constant pressure values for even during the process of forming.

THE AXIAL FORCE OF UPSETTING DETERMINATION

When grouping ribs forming in a tool sets with moving mold segments, the axial force of upsetting appears as the only unmanageable size that changes values depending on other, controlled values such as fluid pressure in the tube, tool stroke etc.

However, the dependence of the axial force on various influential factors can be determined in analytical form [2,5]. The correct determination of the axial force is the basis for the selection of the press equipment on which the forming can be carried out. Generally, the axial force of upsetting can be presented as the sum of the following components:

- F_{a1} - the force required to overcome resistance to plastic deformation occurring in the tube material;
- F_{a2} - the force required to overcome the friction resistance occurring between the tube and the mold;
- F_{a3} - the force required to overcome the pressure of the fluid in the tube on the surface of the punch;

The component F_{a2} is equal to zero because there is no displacement of tube parts inside the mold, i.e. coefficient of friction is zero. The F_{a1} component can be determined by integrating the stress in the meridian direction along the front surface of the tube (circular ring) through which the axial force of upsetting is transmitted:

$$F_{a1} = \int_{R_u}^{R_u + s_0} \sigma_\rho \cdot 2\pi\rho d\rho \tag{9}$$

where is integral limits: R_u internal radius of tube ,

$R_u + s_0 = \frac{d}{2}$ outer radius of tube ,

Radial stress σ_ρ can be define in the form:

$$\sigma_\rho = \frac{\beta K}{2} - p \tag{10}$$

which is obtained from the conditions of the axe symetric deformation state:

$$\sigma_\rho = \frac{\sigma_\theta + \sigma_n}{2}$$

where is σ_ρ and σ_n normal stress in radial and tangential direction of the compensation tube wall respectively [5,6].

The axial force upsetting get the form:

$$F_{a1} = \pi\left(\frac{\beta K}{2} - p\right)\left(s_0^2 + 2s_0R_u\right) \tag{11}$$

By analyzing the expression (11), it is concluded that the axial force upsetting depends on the type of material of workpiece and dimensions of the tube, as well as the pressure of the fluid during process of metal forming. With the increase in pressure in the tube, the required axial force is reduced, which could be expected. As the dimensions of the tubes increase, the required axial force is also increased.

If all the parameters are fixed at one level, the axial force during the process must increase because it also depends on the true stress of material of workpiece K that changes during the process deformation.

Component F_{a3} is defined by the expression:

$$F_{a3} = p \cdot A = p \cdot R_u^2 \cdot \pi \qquad (12)$$

This component of the axial force increases in proportion to the increase in the pressure of the fluid in the tube and the inner diameter of the pipe [6]. The total axial force upsetting is:

$$F_a = F_{a1} + F_{a3}$$

ie. by inserting an expression (11) i (12) :

$$F_a = \pi\left(\frac{\beta K}{2} - p\right)\left(s_0^2 + 2s_0 R_u\right) + \pi \cdot p \cdot R_u^2 \qquad (13)$$

Since the metal forming takes place with constant working pressure in the tube, the axial force upsetting during the formation is monotonous due to the effect of hardening, i.e. an increase in the true stress K, which the experiments confirmed.

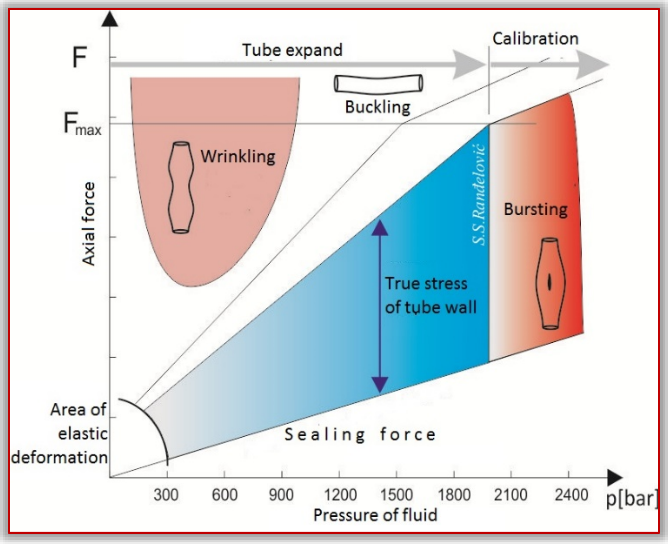

Figure 1. The defect type at hydroforming process

As with any metal forming process, there are certain limitations on the degree of deformation achievable in tube hydroforming process such that parts with desired specifications (like expansions) may not be formed without any defects [8].

Depending on the defect type observed, failure types or instability modes can be grouped as wrinkling, buckling and bursting (Figure 1). Instability modes, which limit the extent of formability in tube hydroforming process, occur when stress and strain state in a part reach a critical level that equilibrium can't be sustained any longer between external forces applied and the internal resistance of the material (i.e. strength).

TECHNOLOGICAL SOLUTION REALISATION

All the complexity of the previously described mathematical procedure gets important when considering the preparation and the finished part after deformation (Figure 1).

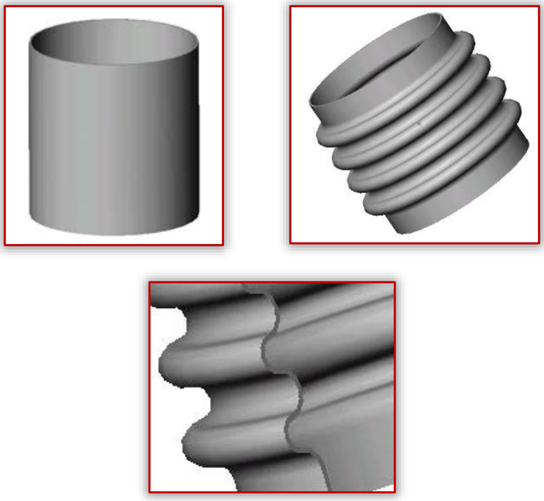

Figure 2. Workpiece a) and finished part b) with geometry of final cross section

The conclusion is immediately drawn that the finished part in Figure 1b, c is almost impossible to obtain by conventional deformation procedures. However, a partial answer to this question is already shown in Figure 2, which only shows the outer appearance of the tool enclosure in a 3D presentation where clearly the outer contours of the tools with the inlet and outlet pipes of the working fluid, that is, the adjoining tools for the press workpiece can be clearly seen.

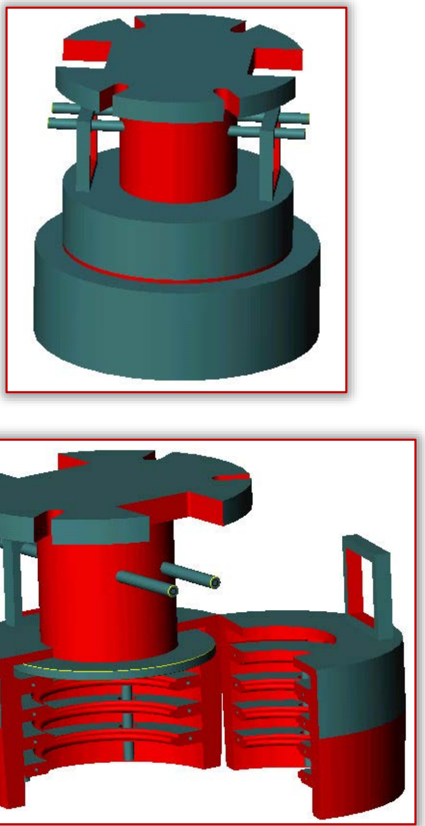

Figure 3. 3D model of tool for compensation tube and flat opening

The very essence and constructive solution of the interior of the tool is clearly seen in Figure 3 which provides an answer to many questions regarding the work of the tool itself. In order to clarify many dilemmas, the same pisture shows the internal geometry of the tool and gives answers to almost all of the reader's questions. This approach and display of tools in many ways helps in understanding the technological method of closing the tool and the deformation process that takes place inside its interior.

CONCLUSION

The production of a compensation tube with an incompressible fluid has a number of advantages over the production of solid tools. A process with movable mold segments is particularly suitable. The paper was intended to provide basic notions and settings of theoretical analysis, thus obtaining the expressions for calculating the required pressure and axial compression forces. In order to verify the theoretical results, complete experimental tests and checks of all parameters were performed.

Note:

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References

[1] B. Musafija, Primjenjena teorija plastičnosti I i II (1973), Sarajevo, str. 684.
[2] Koc M., Altan T., Prediction of forming limits and parameters in the tube hydroforming process, Machine tools & Manufacture, 2001. p.123-128
[3] Slater R.A.C., Engineering Plasticity, Theory and application to metal forming processes, 1977., London
[4] Marciniak, Z., Duncan J.L., Hu S.J., Mechanics of Sheet Metal forming (2002), Butterworth-Heinemann (p. 211)
[5] Jansson, M, Nilsson, L., Simonsson, K., The use of biaxial test data in the validation of constitutive descriptions for tube hydroforming applications, Journal Material Processing Technology, 2007, 184, p. 69-76
[6] Hartl, Ch., Research and advances in fundamentals and industrial applications of hydroforming, Journal Material Processing Technology, 2005, 167, p. 383-292
[7] Manabe, K., Amino, M., Effects of process parameters and material properties on deformation process in tube hydroforming. Journal Material Processing Technology, 2002, 123, p. 285-291
[8] Ranđelović S., Marinković V., Proizvodne tehnologije, Mašinski fakultet u Nišu, 2017. p. 356.

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