ANALYTICAL MODEL FOR FRICTION COEFFICIENT DETERMINATION IN TUBE HYDROFORMING PROCESS

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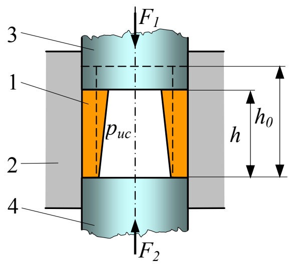
ABSTRACT
The influence of friction on load of die in hydroforming process has a major impact. Regardless that hydroforming process is considered to be the process with reduced friction or very low intensity of friction, still this phenomenon in hydroforming process is field of interest for many scientist. Many authors have been defined analytical models for friction coefficient determination for symmetrical shapes. These analytical models gives different values then real measured ones therefore in these models was not included influence of workpiece free expansion zone. In this paper analytical model for friction coefficient determination is given depending on flowing parameters: workpiece material, tube wall thickness, fluid pressure and workpiece deformation ratio. Analytical model is practical for application and describes real hydroforming process. In paper experimental method for friction coefficient measuring is given for tube hydroforming.
Keywords: analytical model, friction coefficient, hydroforming, tube

1. INTRODUCTION
Friction between die and the workpiece in hydroforming processes significantly influences to material flow which makes it decisive parameter in setting working pressures for forming process. The influence of friction can be evidenced in micro structural chances of material that has been deformed, die wearing and increased energy consumption for forming process. When it comes to forming process in simulation of volume forming process, contact friction conditions are continually changed during the process and represents complex analytical problem, making it difficult to obtain reliable friction mathematical model. The results of numerical simulations depend strongly on boundary conditions, which, among other things, refer to the contact friction. Additionally, a key step in the physical simulation of processes is the selection of appropriate lubricants, in order to establish the conditions of similarity of real and modulated process and the validity of modeling results. It is known that experiments which parameters are material very well illustrate the behavior of real materials in forming process, so it is completely understandable that the tribological mechanism in model experiments similar, and as complicated as the real processes. All researches of friction in forming processes leads in two directions: defining of friction mechanism over low and theory of friction and development of methods for involvement of these definitions in forming process models and quantitative estimation of friction parameters. Friction influence on die loads in tube hydroforming process is of great importance. Regardless that hydroforming process is considered to be the process with reduced friction or very low intensity of friction, still this phenomenon in hydroforming process is field of interest for many scientist [1-11].

2. ANALYTICAL MODELS FOR FRICTION COEFFICIENT DETERMINATION

Although the hydroforming process is considered to be the process with reduced friction, still is on the loupe of many researches where some of them obtained analytical models for friction coefficient determination. Author [5] has presented his model for friction coefficient determination in hydroforming process. Analytical model for friction coefficient determination is given for symmetrical workpieces – tube diameter (d_0) and initial height (h_0), presented at figure 1 for hydroforming process, where:

1- workpiece - tube,
2- die,
3- upper movable punch and
4- lower fixed punch.



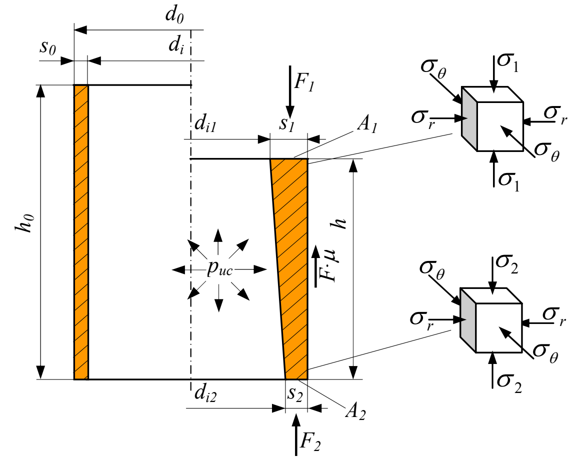


Figure 1. Tube hydroforming process and forces in hydroforming process

If is assumed that the stress in contact of tube and die is (σ_k) $\sigma_k = p_{uc}$ [11] come to the analytical model for friction coefficient determination:

$$\mu = \frac{1{,}15k\begin{Bmatrix}\left(d_0^2 - d_{i1}^2\right)\cdot\left[\ln\left(s_1\left(d_0 - s_1\right)/s_0\left(d_0 - s_0\right)\right)\right]^n - \\ \left(d_0^2 - d_{i2}^2\right)\cdot\left[\ln\left(s_2\left(d_0 - s_2\right)/s_0\left(d_0 - s_0\right)\right)\right]^n\end{Bmatrix} + p_{uc}\cdot\left(d_{i2}^2 - d_{i1}^2\right)}{4\cdot p_{uc}\cdot d_0\cdot h} \tag{1}$$

where: s_0 – initial tube wall thickness; s_1 – tube wall thickness in contact with upper punch; s_2 – tube wall thickness in contact with lower punch; p_{uc} – fluid pressure in tube; h – current high of tube; d_{i1}, d_{i2} – tube inner diameter at upper and lower part of tube; d_i – initial tube inner diameter.

Based on the equation (1) it can be seen that friction coefficient in hydroforming process between workpiece and die is function by following parameters:

$$\mu = f\left(s_0, s_1, s_2, h, d_0, p_{uc}, k, n\right) \tag{2}$$

where: (s_0, s_1, s_2, h, d_0) – geometrical parameters showed at figure 1; n – defined with experiment. Authors [9] analytical model for friction coefficient determination obtains through analysis of stress in various zones and use experiment to get friction force. To obtain this analytical model elementary part is analysed in linear zone and free zone expansion of workpiece as shows figure 2.

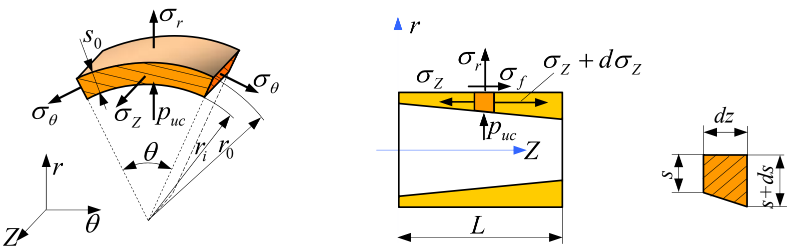


Figure 2. Analysis of elementary part stress in plane Orθ and Orz

Using analysis of stress and deformation for whole tube authors [9] obtained following analytical model for friction coefficient:

$$\mu = \frac{(2\alpha - 1)\cdot s_0}{L}\ln\left(\frac{F_t}{4\cdot\pi\cdot r_0\cdot p_{uc}\cdot(\alpha-1)\cdot s_0}+1\right) \tag{3}$$

where: F_t – friction force experimentally determined; L – tube length; r_0 – outer radius; α – part angle.

3. NEW APPROACH TO ANALYTICAL MODELING OF FRICTION COEFFICIENT DETERMINATION

Differently by authors [10] and their analysis for friction between tube and die in hydroforming process new approach emerged for analytical determination of friction coefficients. Figure 3 shows linear zone and free expansion zone in the tube hydroforming. Before approaching to analytical modelling of friction coefficient it has to be analysed contact between tube and (detail „A“).

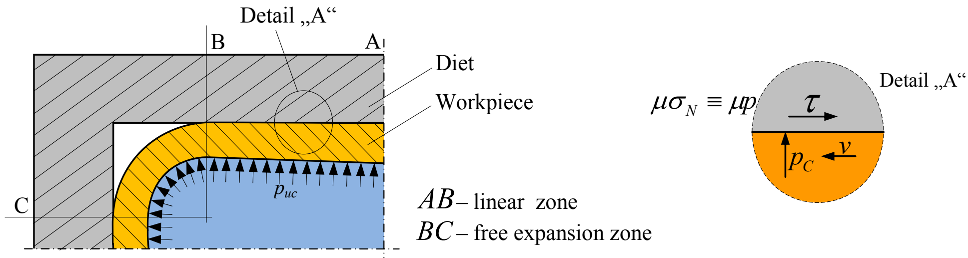


Figure 3. Expansion zones in hydroforming of tube and detail of contact between workpiece and die

Analysing detail „A“ on figure 3 it is possible to come to influence parameters for determination of friction coefficient and contact stress. Friction coefficient (μ) depends on: workpiece material and die coating; surface topology; contact pressure; lubricants; slipping velocity. Contact stress (σ_N) depends on: fluid pressure; axial force; workpiece fitting in die; yield strength of workpiece; modulus of elasticity of die; preliminary workpiece forming. In order to obtain analytical models for determining the coefficient of friction in the hydroforming process, it is necessary to analyze the stress and strain on the linear zone of die based on Figure 3.

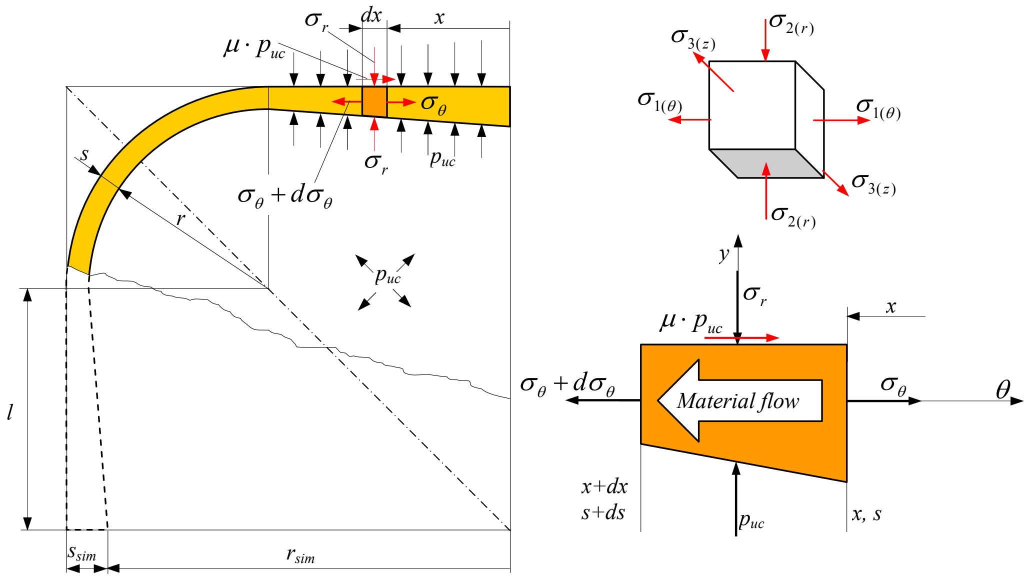


Figure 4. Analysis of stress and deformation in linear zone in tube and elementary part

The analysis of equilibrium conditions, figure 4, observed elementary part of workpiece length dx, unit width, neglecting the size of lower order with $\mu = const$, $p_{uc} = const$ and boundary conditions analytical model is obtained for friction coefficient function between tube and die in hydroforming process:

$$\mu = \frac{p_{uc} \cdot x}{\left[C\left(\frac{2}{\sqrt{3}}\right)^{n+1} \cdot \varepsilon_{\theta}^{n} - p_{uc}\right] \cdot s \cdot e^{-\varepsilon_{\theta}} - \left[C\left(\frac{2}{\sqrt{3}}\right)^{n+1} \varepsilon_{sym}^{n} - p_{uc}\right] \cdot s_0 \cdot e^{-\varepsilon_{sym}}} \tag{4}$$

where: $C = Rm(e/n)^n$ – constant depends of material; n – exponent of hardening curve third order; μ – friction coefficient between workpiece and die ; ε_θ – equivalent deformation in direction θ; ε_{sym} – equivalent deformation in radial direction r; x – observed length.

4. CONCLUSION

If is analysed analytical model presented by author [5] in equation (1) for friction coefficient determination between workpiece (tube) and die in hydroforming process can be concluded that given model does not include the increase of contact pressure due the stress in the outer diameter. This method of determining the analytical model of the friction coefficient is related to the deformation of symmetrical workpieces where it is not taken into account the expansion of the workpiece which are different from the real model of deformation tube hydroforming.
Analytical model for friction coefficient determination presented by author [9], is defined by stress zone analysis, where is given for linear zone of stress which is presented in equation (3). When determining the coefficient of friction is necessary to first experimentally determine the friction force [9]. Model (3) is different from the real model, it is not considered a free zone expansion of the workpiece. A new approach to analytical model for friction coefficient determination in hydroforming [10] takes into account the linear zone and a zone of free expansion of the workpiece, equation (4). The analytical model for friction coefficient determination (4) is a function of the following sizes: workpiece material, workpiece wall thickness fluid pressure and the degree of deformation of the workpiece, is more convenient to use and more realistically describes the hydroforming process.

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