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ONE CONTRIBUTION TO THE INVESTIGATION OF FRICTION IN TUBE HYDROFORMING

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ABSTRACT
Tube hydroforming (THF) enables manufacturing of different hollow complex shape components. Main application field of THF are automotive industry, lightweight constructions and sanitary appliance. There are many factors which influence the tube hydroforming process. Friction between the tube and the die is one of the very significant parameter which influences the main process parameter as well as the component quality.
This paper illuminates basic process parameters, possibilities and limitations and role of friction in the process. Furthermore, possibilities of friction estimation in elastic and plastic state of the tube are presented. Different friction models are presented. Tube upsetting model has been described. Experimental investigations have been carried out in order to verify the analytical results. Based upon performed investigation relevant conclusions have been drawn.
Key words: Tube hydroforming, friction, analytical model, experiment.

1. INTRODUCTION
Owing to very strong world competition, producer of metal parts are striving to develop and perform the technological processes which are characterized by better material utilization, optimal mechanical properties of manufactured component and time and cost reduction. Under certain circumstances tube hydroforming (THF) offers numerous techno-economical advantages when compared to other sheet metal technologies, especially in the production of complex shape parts. This innovative technology makes possible to produce hollow parts with different complex shapes which are widely used in automobile industry (auto-frame parts, chassis, exhaust systems, camshaft...), in the lightweight constructions but also in sanitary appliances. In Fig. 1 elements of exhaust systems produced by THF are shown.

Figure 1. Components manufactured by THF

Process of THF is carried out by the simultaneous action of internal pressure in the tube and axial upsetting (Fig.2). During the process development friction between the tube outer wall and die inner wall takes place. As contact pressure between the die and the tube is relatively high and contact surface large, high friction force occurs. This force adversely affects process parameters as well as the component quality. Therefore, investigations aiming at clarifying and decreasing friction effects in THF are of great importance.

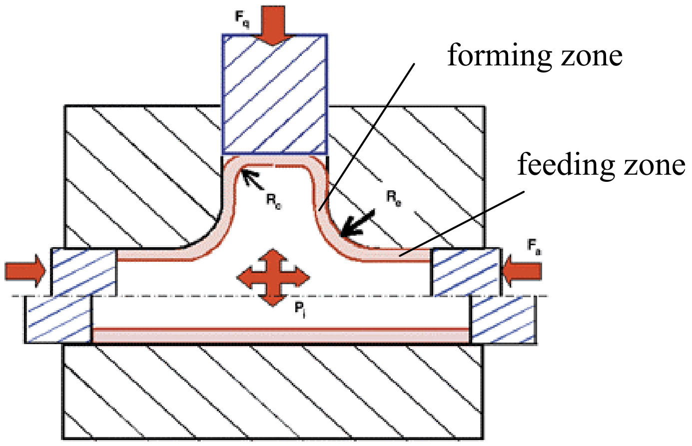

Figure 2. Feed and forming zones in THF process

This paper describes two methods for determination of coefficient of friction (COF) in THF, one for the elastic (feed) zone and another for the plastic deformation zone of the tube.

2. FRICTION MEASUREMENT IN THF

As previously mentioned, two zones in THF process occur: so called »feed zone« which is in elastic state and plastic deformation zone (Fig.2). Friction behaviour in these two zones is different. Most frequently used method for determination of friction coefficient in elastic, feed zone is so called » push through test«. In this test tube under pressure is pushed through the die and during this movement axial force at both ends are measured. Force difference at both ends of the tube indicates the friction force. More details regarding measurement of friction in elastic zone can be found in /5/, /9/.

There are different possibilities for determination of COF in plastic zone. The review of main principles and application of those methods are given in /11/. The current paper illuminates one original method for determination of COF in plastic zone which is based upon the fact that during deformation tube wall deforms differently along the tube high, i.e. wall thickness at the side of movable punch is higher than this at the fixed punch. This is due to friction which occurs between the tube and the die (Fig.3). In Fig.3tube prior and after deformation (upsetting), with all relevant geometrical data, is shown.

In the analytical derivation of μ following assumptions have been introduced:

- Wall-thickness distribution along the tube length is linear
- Axial stress depends only on z-coordinate
- Friction stress is equally distributed along the tube length
- Coulomb friction low is adopted
- Tresca yield criterion is applied

As a result of comprehensive analytical work, following expression for the COF in plastic deformation zone is obtained:

$$\mu = \frac{\beta \cdot C \cdot (A_1 \cdot \varphi_1^n - A_2 \cdot \varphi_2^n) + p_i \cdot (A_1 - A_2)}{[(1{,}15 \cdot \sigma_e + 2 \cdot p_i) \cdot \frac{s}{d_a} + p_i] \cdot d_a \cdot \pi \cdot h} =$$

$$= \frac{1{,}15 \cdot C \cdot \left\{ \left(d_a^2 - d_{i_1}^2\right) \cdot \left[\ln \frac{s_1 (d_a - s_1)}{s_0 (d_a - s_0)} \right]^n - \left(d_a^2 - d_{i_2}^2\right) \cdot \left[\ln \frac{s_2 (d_a - s_2)}{s_0 (d_a - s_0)} \right]^n \right\} + p_i \cdot (d_{i2}^2 - d_{i1}^2)}{4 \cdot [(1{,}15\sigma_e + 2 \cdot p_i) \cdot \frac{s}{d_a} + p_i] \cdot d_a \cdot h} \quad (1)$$

where are:

β - Tresca's coefficient ($\beta = 1.15$)
C, n - Material properties according to the Ludwik-Hollomon-relationship for the flow stress
A_1, A_2 - Cross sections
φ_1, φ_2 - Logarithmic strain

For the determination of COF by using (1) the needed input data have to be acquired by experiment. Detailed derivation of expression (1) can be found elsewhere /11/).

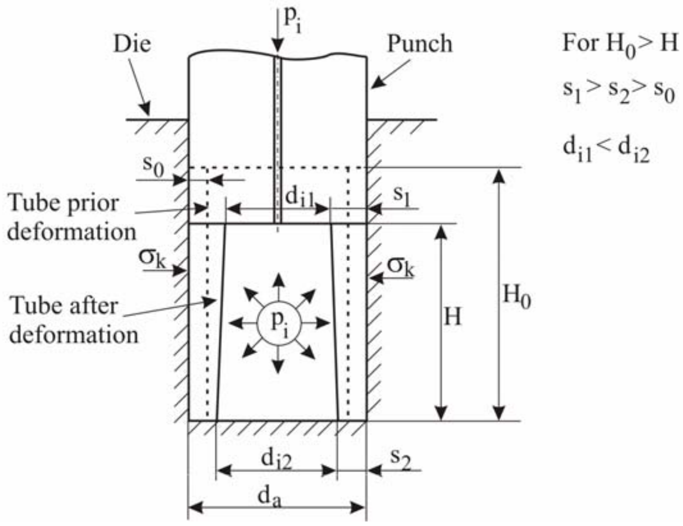

Figure 3. Upsetting of tube under inner pressure

3. RESULTS AND CONCLUDING REMARK

Determination of μ coefficient by (1) requires input data (wall thickness distribution) which were obtained experimentally.

In Fig.4 wall thickness measurement prior and after deformation is shown. As it can be seen, the wall thickness after deformation, at the side of movable punch, is larger than at the side of fixed punch. This thickness difference is main input data in /1/.

The main influential parameters on the coefficient of friction for given technological conditions μ are the inner pressure and punch travel Δh. Fig.5. shows the value of μ calculated according to /1/, using experimental data.

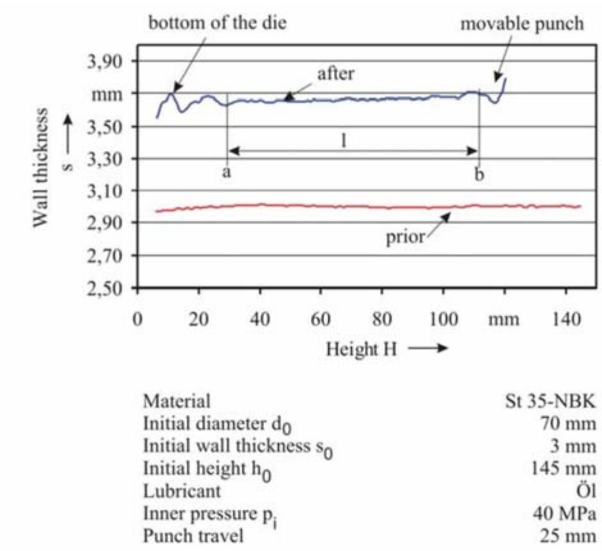

Figure 4. Wall thickness distribution prior and after upsetting

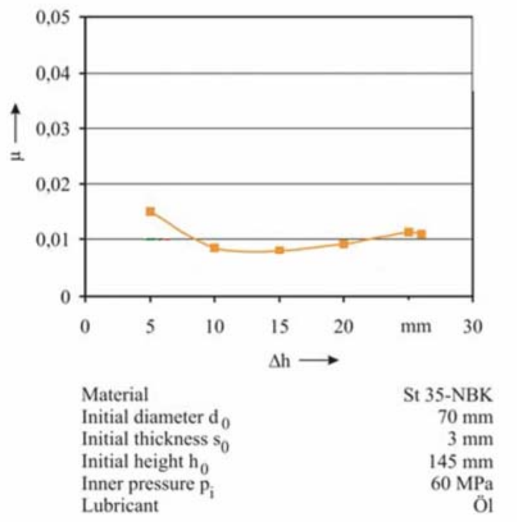

Figure 5. Coefficient of friction

Concluding remarks:

- A new analytical model to determine the friction coefficient (COF) in forming zone of tube hydroforming has been proposed. According to the developed model COF can be calculated on the base of tube material properties and tube geometry prior and after deformation (upsetting). Load measurement is not needed.
- Increasing friction results in increased wall thickness inhomogeneity.
- With increasing inner pressure COF decreases.
- Materials with higher hardening coefficient "n" show lower thickness inhomogeneity and vice versa.
- With increasing inner pressure "p_i" wall thickness difference along the tube height increases too.
- For the same COF value milder materials (e.g. AlMgSi) exhibit higher degree of wall thickness inhomogeneity than it is the case at stronger materials (e.g. St 35).
- Obtained COF values are lower than those determined for feeding zone (reported by Hartl [10]).

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