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Analytical Modeling of Axial Force in Hydroforming of Thin-Walled Tube Elements

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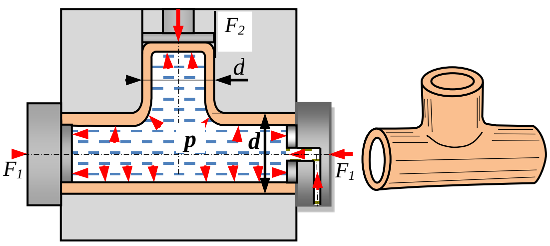
ABSTRACT

Hydroforming of a tube is an advanced process of plastic forming. Researches in this area are significant for an analysis with a view to optimal performance and process improvement. This paper provides theoretical and experimental analysis of the axial force modeling in T tube.

Keywords: *hydroforming, tube, axial force, experiment, modeling*

I. INTRODUCTION

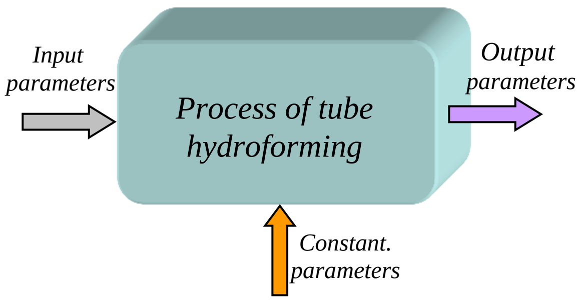
With the implementation of advanced technologies there has been a significant change in automotive and aviation industry due to increased securing and ergonomic conditions. For a long time, the automotive industry utilizes the steel tubes for control system and some other mechanical components. Researches indicate that the European car utilizes more than 46 kg of steel tube, with constant increasing. Besides steel tubes, there has been a significant usage of light and heavy metal tubes. These demands initialized the settlement of the new manufacturing philosophy based on unconventional procedures, including plastic forming with an incompressible fluid. Owing to the rapid development of informational technologies, forming, modeling, optimization, the hydroforming process saves material, maintain mechanical characteristics of the material and some other parameters for the forming process. This paper shows an example of analytic forming of the axial force in T-shape hydroforming of thin-walled tube for three different material, three wall thickness values , with the same input data of the initial tube length and outer tube diameter.



[Fig 1] Scheme of T-shape tube hydroforming

II. ELECTION OF TUBE HYDROFORMING PROCESS PARAMETERS

A number of the input parameters is consistent with real demands and needs which determines the output parameters. A functional dependency of the output parameters determines an election of the variable output dimensions, with a number not so large. A small number of the input parameters facilitate defining of the mathematical modeling process and experiment realisation.



[Fig 2] Scheme of the influential process parameters

The variable-independent input sizes in T-shape tube hydroforming process can be:

- pressure of the flow, σ_V *(N/mm2),*
- height of the bulge, h_1 *(mm),*
- wall-thickness, s_i *(mm),*
- the bias, Δl *(mm)*
- length of the tube, l_0 *(mm)*
- diameter of the tube, d_i *(mm)*
- diameter of the bulge, d' *(mm)*

The variable-dependent output sizes of the hydroforming process:

- the axial force, $Fa\ (N)=f\ (d_0\ ,\ s_0,\ \sigma_{0.2},\ p_{uc},\ \Delta l,\ H_i)$

III. EXPERIMENTAL ANALYSIS

Experimental analysis demands defining of the terms of experiment performing, with precisely identified parameters of the forming process, and resources needed for the experimental performance. For experimental performance there were used:

- a device for fluid plastic forming with the equipment,

- tube forming element die,
- tube element (aluminium alloy AIMgSiO.5, brass – Cu&3Zn, and steel Ck10),
- measuring equipment, measuring amplifier device, Spider 8, from Hottinger Baldwin Messtechnic (HBM), Germany, which is compatible with a computer,
- fluid (oil) for tube hydroforming.

a. Tube hydroforming equipment

The procedure of fluid plastic hydroforming has been conducted in an equipment containing principal components of the hydroforming system, these are:

- the pressure device or closing system,
- the pressure systems or pressure increasing devices,
- a hydraulic cylinder and printer,
- an instrument,
- process control system: a computer and the computer measuring equipment.

[Fig 3] Equipment for experimental analysis of tube hydroforming process

b. Element tube hydroforming die

A T-shape tube hydroforming die has been made of 42CrMo4, where the procedure of the cementation was performed afterwards, with the process quality of an N5, lapped and abraded.

[Fig 4] T-shape tube hydroforming die

c. Tube element for T-shape tube hydroforming

For experimental analysis there has been utilized the tubes made of three types of material: aluminium alloy, brass and steel. The layout of the initial tube shape is given in Figure 5.

[Fig 5] Initial tube shapes: a) aluminium alloy, b) brass, c) steel

The initial setting dimensions are:

- outer diameter d_v*=20 (mm)* and
- tube length *lo= 80 (mm)*.

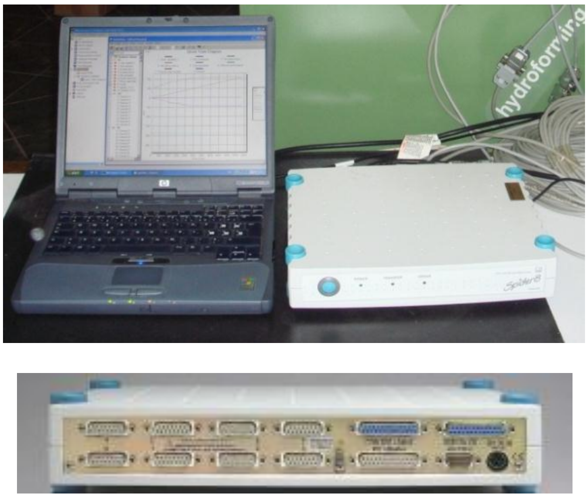
The material characteristics are given in the Table 1.

Table 1:Characteristics materials

Material	Mechanical characteristic		Chemical characteristic
	$R_{0.2}$ [N/mm^2]	R_m [N/mm^2]	
AlMgSi0.5	164	175	*Al*- 98.5 % *Mg -1.0 %* *Si - 0.5 %*
Cu63ZN	412	428	*Cu* - 63 % *Zn* - 37 %
Ck10	290	380	*C* - 0.10 % *Si* ≤ 0.10 % *Mn* ≤ 0.30 % *P/S*≤ 0.035 %

d. Measuring equipment-Measuring amplifier device

The measuring amplifier device, Spider 8 from Hottinger Baldwin Messtechnick (HBM), Germany, has been used for measuring the output dimensions, whose work is compatible with a computer. The device contains eight independent measuring channels, where various sensors can be connected, based on principle of the electronic dimension change, Figure 6.



[Fig 6] **Measuring amplifier device Spider 8**

[Fig 7] Dynamometers for axial force measurement

e. Tube hydroforming fluid

Hydraulic system of devices for hydroforming is full with the fluid (oil) NOL HIDROL-X46.

f. Experimental plan performance

For modeling of T-shape hydroforming process one matrix test has been used:

$$N = r^k + n_0 \qquad (1)$$

where:

- $r = 2$ – level number,
- $k = 3$ – factor number,
- $n_0 = 4$ – repetitive experiment number.

A number of tests in this experiment:

$$N = 2^3 + n_0 = 8 + 4 = 12$$

The mathematical model shape: $y = b_0x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{23} x_2 x_3 + b_{13} x_1 x_3 + b_{123} x_1 x_2 x_3$ (2)

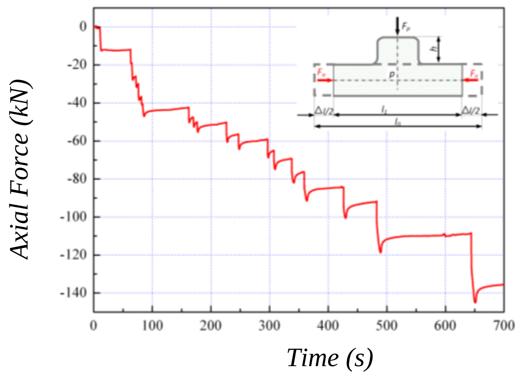
g. Experimental results of axial force measurement

The diagram shows natural, coded and experimental results used for analytic modeling of the axial force in T-shape tube hydroforming.

Table 2: The results of axial force experimental measurement

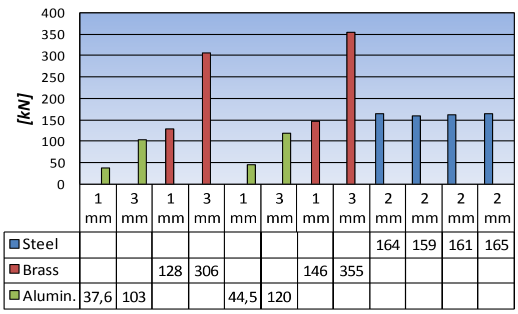
No. Expe. (Nj)	Natural value			Encoded value			Experi. value
	s_0	$\sigma_{0.2}$	Δl	X_1	X_2	X_3	F_a
	mm	N/mm^2	mm	-	-	-	kN
1	1	164	10	-1	-1	-1	37.6
2	3	164	10	1	-1	-1	102.8
3	1	412	10	-1	1	-1	128.0
4	3	412	10	1	1	-1	306.1
5	1	164	20	-1	-1	1	44.5
6	3	164	20	1	-1	1	119.7
7	1	412	20	-1	1	1	146.0
8	3	412	20	1	1	1	355.2
9	2	290	15	0	0	0	164.4
10	2	290	15	0	0	0	158.7
11	2	290	15	0	0	0	161.0
12	2	290	15	0	0	0	164.5

The diagram shows the measured dimensions for axial force of T tube forming, made of steel (wall thickness s_0=2 mm).



[Fig 8] Axial force measured with the measuring amplifier device, Spider 8 from Hottinger Baldwin Messtechnick (HBM)

Axial force values for twelve measurements are given in Figure 9.



[Fig 9] The diagram of the experimental measured values for axial force

IV. ANALYTICAL MODELING OF AXIAL FORCE

Analytical modeling is the procedure of defining equations of state of processes or systems.

a. The final mathematical model

After determining the significance of the polynomial coefficients (b_i) of the mathematical model, the regression equation is obtained, i.e. the mathematical models for determined various depended variable in its final shape, with coded values of the input variables.

$$y = 157,400 + 65,962X_1 + 78,837X_2 + 11,362X_3 + 24,600X_1X_2 + +5,412X_2X_3 + 5,137X_1X_3 \quad (3)$$

The final shape of the mathematical model

$$F_a = -8,912 - 6,585s_0 + 1,08\sigma_{0.2} - 2,296\Delta l + 0,198s_0\sigma_{0.2} + +1,027s_0\Delta l + 0,008\sigma_{0.2}\Delta l \quad (4)$$

The final shape of the mathematical model is obtained by substitution of coded values with numerical values of the influential parameters of T tube hydroforming process.

V. CONCLUSION

The process of tube hydroforming is mostly utilized in automobile and aviation industry, where techno-economic, securing and ergonomic conditions are at the highest level. In this respect, an application of the parameter modeling methods of the forming processes is significant. This paper provides an example of the final mathematical model obtained for defined process conditions: three types of material (AL alloy, brass and steel), three wall thickness (1-2-3 mm) and axial printer course (10-15-20 mm). The applications of obtained results gives options for the parameter optimization in the tube forming process with incompressible fluid.

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