DETERMINE PARAMETERS HYDROMECHANICAL BULGE FORMING OF AXISYMMETRIC COMPONENTS MADE FROM COPPER TUBES

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Abstract

The investigations into the hydromechaymponical bulge forming involved the use of copper tubes at the relative ratio $s_o / D = 0.04$ (where s_o is the wall thickness and D is the tube diameter). The experimental results of bulge forming of axisymmetric components are presented. The paper gives the force waveforms and the pressure changes obtained at relative displacement $\Delta l / l_0 = 0.06$ (where Δl displacement, l_0 initial length of tube). Both the axial force and liquid pressure increased with an increase in the relative displacement $\Delta l / l_0$. The maximum value of the force amounted to 83,69 kN and the highest value of the pressure was noted (60 MPa) at ratio $\Delta l / l_0 = 0.06$. The analysis of wall thickness distribution in logitutudinal and cross sections hydromechanically bulged axisymmetric component at ratios $s_0 / D = 0.04$ and $\Delta l / l_0 = 0.06$ was made. The technological parameters (liquid pressure, axial loading) were determined, which may provide guidelines when the method is implemented into production.

Keywords: Hydromechanical bulge forming, hydroforming, axisymmetric component, the wall thickness distribution

1. INTRODUCTION

The process of hydromechanical bulging is a type of liquid pressure forming, in which the external upsetting force is additionally applied. The exerted pressure is intended, first of all, to image the shape of the die impression that has the pre-set outer dimensions of the connection. The upsetting force, on the other hand, causes the material flow in the axial direction, thus making it possible to obtain branches of substantial length [1]. In most publications the process of hydromechanical bulge forming is called hydroforming process but the concept of hydroforming has wider significance and includes the processes of material forming by liquid pressure without an external upsetting force, too. The basic parameters of the hydromechanical process of bulge forming are: liquid pressure and axial loading.

The process is employed while manufacturing pipe connections, including axisymmetric components. Copper pipe connections are used in hydraulic, heating, gas and waste water systems, [1-3]. The technology involves placing a tube segment in a die-cavity, pouring some liquid over it, and sealing the faces. As it can be seen from **Fig. 1**, the rising pressure of the liquid upsets the pipe. As a result, we can obtain bulged axisymmetric component with different ratio h / d_1. The shape and dimensions are presented in **Fig. 2.**

The investigations conducted for many years by J. Chalupczak et al. [1,4-7] have demonstrated that the method makes it possible to manufacture T-pipes of all steel types used in pipeline construction, equal and reducing tees ($d / D = 1 \div 0.6$), straight and skewed tees ($\alpha = 45 \div 90^0$, where α denotes the branching angle between the pipe branch and the pipe body) as well as steel and copper cross-joints. The method of hydromechanical bulging can be applied to the manufacture of tees of pipes whose wall thickness is $0.033 < s_0 / D < 0.084$ and the ratio of the branch length to its outer diameter $h / d < 1.25$. In his works, the patent author conducted theoretical investigations based on the theory of plastic flow. The equations that determine the stresses in the T-pipe body, a new formula for the upsetting force, as well as formulas to calculate the maximum liquid pressure in bulging and the permissible range of the liquid pressure changes were all derived. Moreover, on the basis of his investigations, with the use of statistical analysis, the author computed equations to determine the initial length of the pipe, the length of the pipe branch and the wall thickness in tee and cross-joint bodies [1].

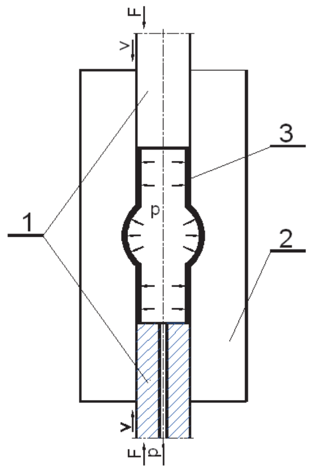


Fig. 1 Hydromechanical bulge forming of axisymmetric component, where: 1 - punches, 2 -die, 3 - component

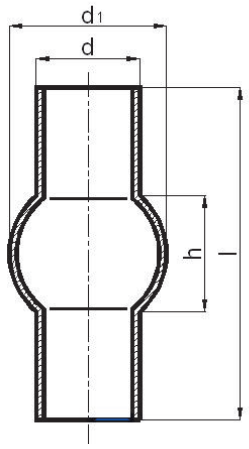


Fig. 2 Shapes and dimensions of axisymmetric component

In recent years, investigations into hydromechanical bulge forming of reducing and equal pipe connections have continued. Some studies on the process of hydroforming have been reported [8-12]. They have been both experimental and computer modeling investigations.

Ray and Mac Donald [8] formed X- and T- branch components using a tube hydroforming machine and compared the results with FEA simulations (LS-DYNA3D). Experiments conducted, estimation of the process and geometric parameters for hydroforming of SS 304 skewed T-pipe (Y shapes) were discussed in study by Jirathearanat et al. [9]. Results of FEA simulations (ABAQUS) for three unequal T joints were verified by experiment and the effects of different parameters (coefficient of friction, strain hardening exponent and fillet radius) on the protrusion height, thickness distribution, and clamping and axial forces were studied [10]. Nikhare C. P. et al. [11] conducted experimental and numerical analysis of low pressure hydroforming for 409 stainless steel tubes. It is found that it reduces the internal fluid pressure and die closing force for producing the hydroformed part without buckling. In 2012, Joo B-D et al. [12] demonstrated that a flanged automotive part can be formed using the hydroforming process without additional stages such as bending and pre-forming. The research on the hydroforming involved using HF440 steel tubes with the outside diameter of 65mm and wall thickness of 2 mm. In his study, Joo B-D analyzed hydroforming characteristics at various pressure conditions and compared experimental results with the finite element simulation results (DYNAFORM).

The paper presents experimental results that concern hydromechanical bulging of axisymmetric component from copper tubes, whose relative wall thickness was $s_o / D=0.04$. Hydromechanically bulged specimens were obtained at relative displacement $\Delta l/l_0=0.06$ and ratio $h/d_1=0.67$ (**Fig. 2** shows the notations). The aim of experimental investigations was:

- for axisymmetric components, to determine the force waveforms and the pressure changes;
- to analyze of wall thickness distribution in logitutudinal and cross sections hydromechanically bulged axisymmetric component.

2. METHODOLOGY

The material for experimental investigations were copper (Cu99,E) tube segments, whose outer diameter was D = 22 mm and the wall thickness s_0 = 1mm, (which corresponded to the relative thickness s_0 / D = 0.04). The initial lengths of tube segments were 115mm.

Hydromechanical bulging of components was performed at the stand which included the following:

- a tool for hydromechanical bulging of connections equipped with replaceable die inserts presented in **Fig. 3**;
- ZD100 testing machine modified by LABORTECH firm, 1MN force (machine calibrated by PN-EN ISO 7500-1:2005 and meets the metrological requirements for class 1);
- hydraulic feeding system, the most important component of which was hand-operated pump building up pressure 0 ÷ 150 MPa;
- computer stand with Test&Motion software (LABORTECH) to measure forces and displacements.

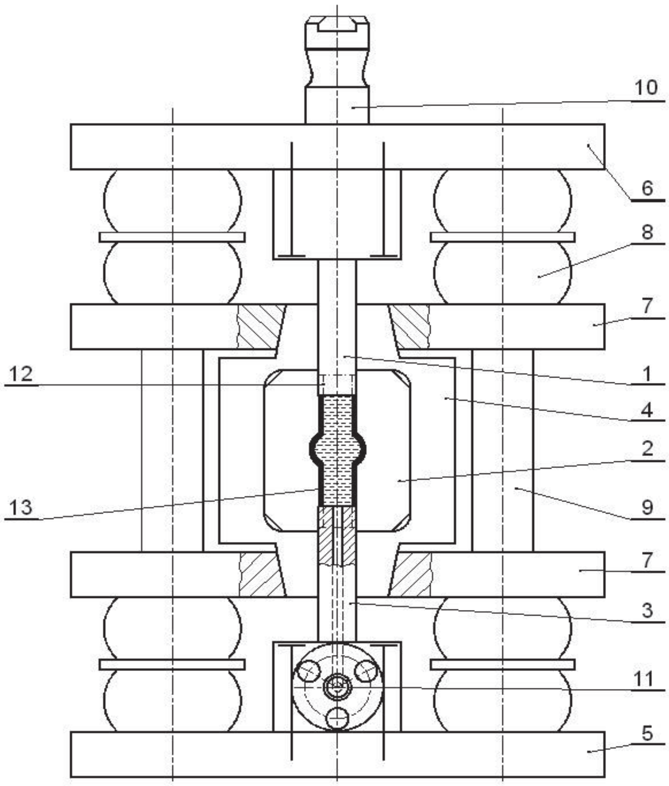


Fig 3 The hydromechanical bulge forming tool, where: 1-upper punch, 2- die insert, 3- lower punch, 4- half-die, 5- lower die block, 6- upper die block, 7- pressure platens, 8- rubber rings, 9- guide-posts, 10- fixing pin, 11- liquid feed, 12- tube segment, 13- hydromechanically bulged axisymmetric component

The measurements of pressure were taken with pressure transducer NPXG 1000, the range of which was 0÷100MPa. The transducer was manufactured by PELTRON company based in Warsaw. The voltage signal was transmitted to one of the channels of the card of 12-bit analog-digital converter LC 011-1612 of Ambex company. With the use Test&Motion software controlled by LaborTech electronic (external digital controller EDC), it was possible to present the experimental data in the form of graphs showing the values of forces as the function of displacement.

3. EXPERIMENTAL RESULTS AND ANALYSIS

Experimental investigations consisted in the hydromechanical bulging of axisymmetric components at the constant upsetting ratio $\Delta l / l_0$ = 0.06. Examples of experimentally bulged parts from copper tubes obtained in experimental investigations at ratio s_0 / D = 0.04 are presented in **Fig. 4**.

For hydromechanical bulge forming in accordance with the diagram in **Fig. 1**, the bulging coefficient is defined in the literature [4] as follows (denoted in **Fig. 2**):

$$k_r = \frac{d_1}{D} \qquad (1)$$

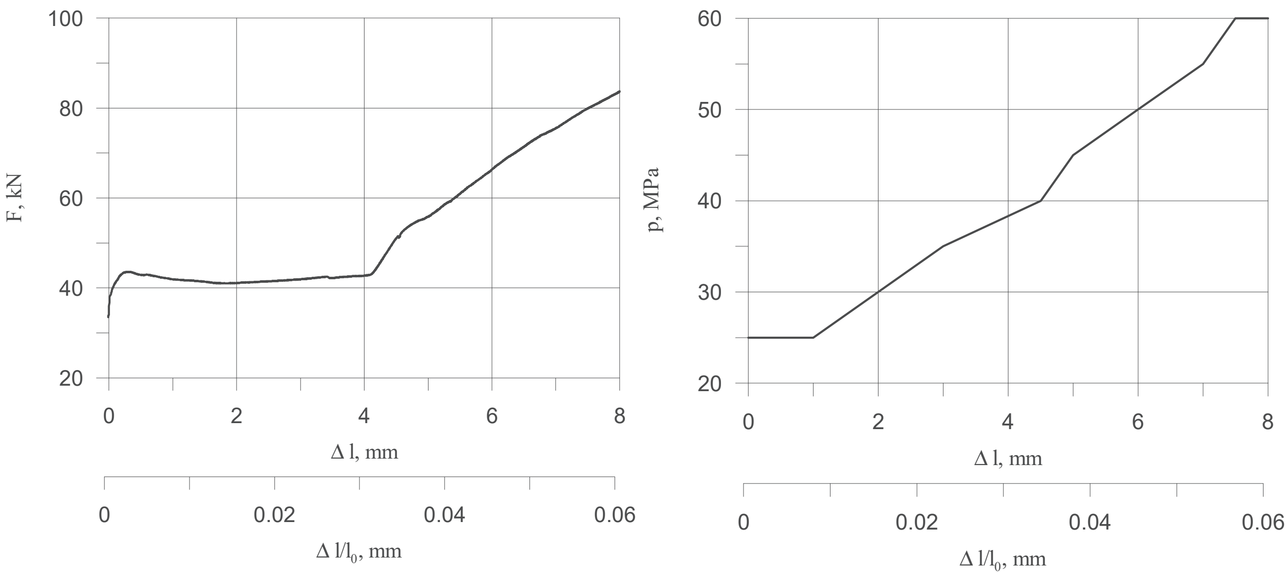
where: d_1 - the largest diameter of the cup, D - the initial external tube diameter.

Its value experimentally obtained (k = 1.36) was higher than the admissible the maximum coefficient presented in the literature [2] for bulging pressure of the liquid from copper tubes (k = 1.33). The ratio h/d_1 was 0.67 for successfully hydromechanically bulged elements (**Fig. 2** shows the notations).

a) b) c)

Fig. 4 Hydromechanically bulged axisymmetric components from copper tubes at ratio s_0 / D = 0.04: a) successfully bulged specimen obtained at relative displacement $\Delta l/l_0$=0.06; b) the same specimen after machining; c) specimen with broken spherical cup in the initial stage of hydromechanical bulge forming

For the abovementioned connections, pressure patters and changes in force are shown in **Fig. 5**. It should be noted that experimentally obtained patterns of pressure and force start at certain initial values, determined experimentally that made it possible to initially bulge a tube segment. That was necessary to make pits in pipes faces with the punch conical protrusion so that the pipes could be sealed.



a) b)

Fig. 5 Force vs. displacement (a) and liquid pressure vs. displacement (b) obtained for hydromechanically bulged axisymmetric component at ratios s_0 / D = 0.04 and Δl / l_0 = 0.06

For the specified pressure patters and changes (**Fig. 5**) and ratio Δl / l_0 = 0.06, an exact representation of die-cavites with diameter of cup d_1 = 30 mm was obtained. The maximum value of the force for axisymmetric components amounted to 83,69 kN, and the highest value of the pressure was noted (60 MPa) at ratio

$\Delta l / l_0 = 0.06$. Exceeding this pressure path (about 25 %) resulted in a burst at the spherical cup (as shown in **Fig. 4c**).

In the last stage of investigations, the analysis of the distribution of the wall thickness in axisymmetric component was made. Connections obtained at the constant upsetting ratio $\Delta l / l_0 = 0.06$ and similar changes in pressure were cut along longitudinal and cross sections. The measurements were taken with coordinate measuring machine Prismo-Navigator by Zeiss OKM Jena company, the measuring accuracy of which was up to 1 µm [13]. The results of measurement of wall thickness are presented in **Fig. 6**.

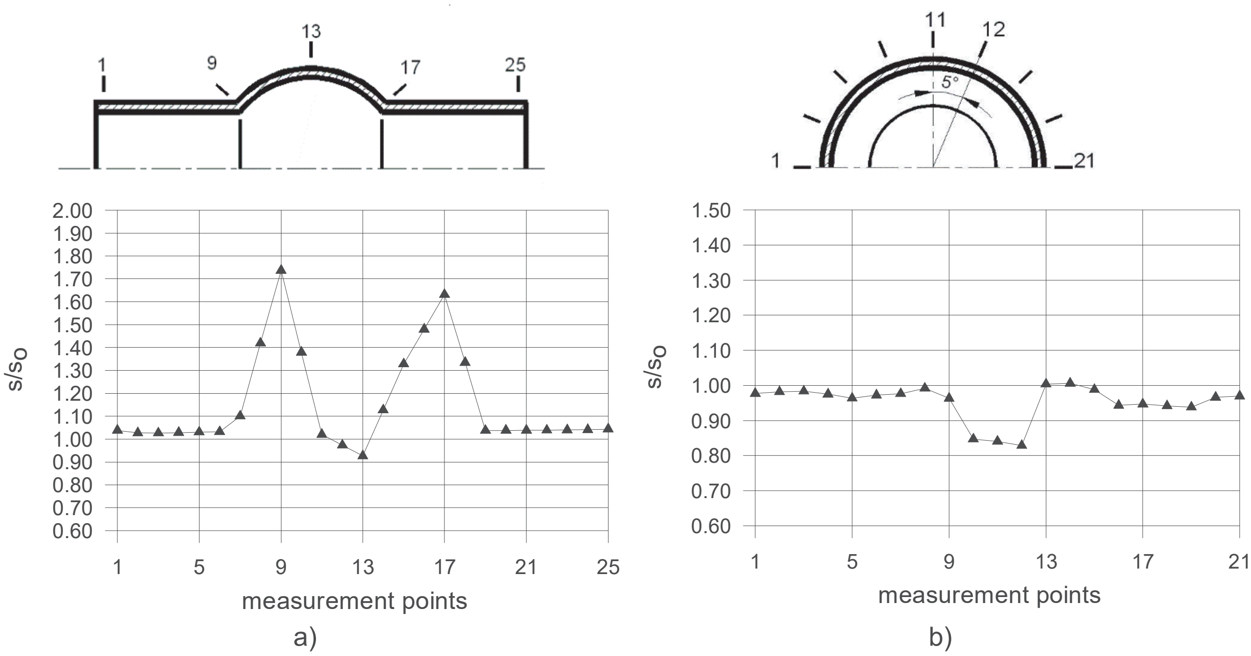


Fig. 6 The wall thickness distribution in logitutudinal (a) and cross (b) sections hydromechanically bulged axisymmetric component at ratios $s_0 / D = 0.04$ and $\Delta l / l_0 = 0.06$

Thickness measurements of test samples did not demonstrate relevant differences. For all connections under consideration at $\Delta l / l_0 = 0.06$, in the longitudinal section (**Fig. 6a**), the greatest wall thickening, maximum approx. 70 %, occurred on the radii of body transition to the spherical cup (measurement points no. 9 and 17 shown in **Fig. 6a**). The wall thinning of 3-7 % was found to appear in the caps. The wall thinning of 2-18 % was found in the cross section of the spherical cap (**Fig. 6b**).

CONCLUSIONS

On the basis of investigations carried out into hydromechanical bulge forming of axisymmetric components, it can be stated as follows:

1. It was possible to conduct hydromechanical bulge forming of axisymmetric components from copper tubes at $s_0 / D = 0.04$. It is confirmed by successfully performed tests at their relative displacement up to $\Delta l / l_0 = 0.06$.
2. Both the axial force and liquid pressure increased with an increase in the relative displacement $\Delta l / l_0$.
3. The value of the bulging coefficient ($k = d_1 / D$) experimentally obtained ($k = 1.36$) was higher than the admissible the maximum coefficient presented in the literature [2] for bulging pressure of the liquid from copper tubes ($k = 1.33$).

The results obtained in the experiment might be used as guidelines to develop a technological process for manufacturing such type of connections with the method of hydromechanical bulge forming. They also could be helpful while applying the method to industrial practice.

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