EFFECT OF THE UPSETTING RATIO ON WALL THICKNESS DISTRIBUTION IN LONGITUDINAL SECTION OF HYDROMECHANICALLY BULGED AXISYMMETRIC COMPONENTS MADE FROM COPPER TUBES

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Abstract

The paper presents experimental results that concern hydromechanical bulging of copper axisymmetric components whose relative wall thickness was s_0 / D = 0.045. The investigations aimed to determine the impact of degree of deformation on wall thickness distribution in longitudinal section of hydromechanically bulged axisymmetric components. The degree of deformation of material was defined as relative upsetting ratio $\Delta l / l_0$ (where Δl - the punch displacement, l_0 - initial length of tube). Changes in the wall thickness distribution in longitudinal sections of hydromechanically bulged copper axisymmetric components with different ratio $\Delta l / l_0$ = 0.054 ÷ 0.109 were similar in character. The greatest wall thickening occurred on the radii of body transition to the spherical cup. The wall thinning was found to appear in the caps. The wall thickness in the cylindrical part of the axisymmetric components was compared with the initial thickness of the tube s_0. The maximum thickening and thinning of the wall were found in the samples with the greatest $\Delta l / l_0$ = 0.109.

Keywords: Hydromechanical bulge forming, hydroforming, upsetting ratio, axisymmetric components, all thickness distributions

1. INTRODUCTION

Hydroforming is a young technology which is currently enjoying increasingly widespread application in industry [1, 2]. The hydromechanical bulge forming is one of the hydroforming techniques, appears to be an interesting method for the manufacturing pipe connections, including T-pipes, Y-shapes (3-way connectors with an angled branch), X-shapes (cross-joints) and axisymmetric components [1-3]. Examples of axially symmetrical and local expansion [4, 5] are presented in **Figure 1**.

Figure 1 Axially symmetrical and local expansion [4, 5]

Copper pipe connections are used in hydraulic, heating, gas and waste water systems. The process is a type of liquid pressure forming, in which the external upsetting force is additionally applied. It consists in placing a tube segment in a die-cavity, pouring some liquid over it and sealing the faces. As a result the liquid pressure rises and the pipe is upset [3]. The basic parameters of the hydromechanical bulge forming process are: liquid pressure and axial loading. A special feature of this method is the lack of undesired heat effects, cleanness and quick joining procedure along with an easy implementation [6]. The following failure modes can occur when tubes with a straight longitudinal axis are being expanded: buckling, bursting, wrinkling and folding back [1 - 3]. The investigations of hydromechanical bulge forming conducted for many years by J. Chałupczak et al. [3, 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, straight and skewed tees as well as steel and copper cross-joints. Chalupczak [3] analyzed distribution of wall thickness distribution in longitudinal and cross sections of hydromechanically bulged T-pipes and X-joints for different parameters (liquid pressure and axial loading) [3]. In recent years, investigations into hydromechanical bulge forming of one-sided and two-sided skewed connections have continued [4, 5]. Some studies on the process of hydroforming have been reported [3, 6, 8 - 16]. They have been both experimental and computer modelling investigations. Ray and Mac Donald [8] formed X- and T- branch components using a tube hydroforming machine and compared the results with FEA simulations. 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. Stadnik et al [12] described FEM simulations (ABAQUS) and experiments for hydroforming of Y-shapes made from stainless steel tubes. The influence of the forming conditions, such as the hydraulic pressure and axial force, on the hydroforming of Y-shapes was investigated. Maeno T. et al. [13] demonstrated that the control of wrinkling for the tube hydroforming is effectice in improving the formability. In her paper [14], Sadłowska discusses the application of modified forming limit diagram (FLD) for hydroforming of X-shapes from copper tubes. Joo B-D et al. [15] 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). Kridli et al. [16] discussed the effects of the strain-hardening exponent, initial tube wall thickness, and die corner radii on corner filling and thickness distribution of the hydroformed tube.

The paper presents experimental results that concern hydromechanical bulging of copper axisymmetric components whose relative wall thickness was s_0 / D = 0.045. The investigations aimed to determine the impact of degree of deformation on wall thickness distribution in longitudinal section of hydromechanically bulged axisymmetric components. The degree of deformation of material was defined as relative upsetting ratio $\Delta l / l_0$ (where Δl - the punch displacement, l_0 - initial length of tube) [3 - 5, 17].

2. METHODOLOGY

The material for experimental investigations were copper (Cu99, E) tube segments (from seamless tubes), whose outer diameter was D = 22 mm and the wall thickness s_0 = 1 mm (which corresponded to the relative thickness s_0 / D = 0.045). The initial lengths of tube segments were l_0 = 110 mm. In this study, pure copper was selected as the testing material due to its excellent formability and a wide range of industrial applications [18]. Additionally, copper pipe connections are used in hydraulic, heating, gas and waste water systems [1 - 5]. The microstructure of copper was observed using a Nikon ECLIPSE MA 200 optical microscope. It is shown in **Figure 2**. The mechanical properties of copper tubes were determined by static tensile testing (R_m = 268 MPa, A = 29.7 % [5]). The microhardness values of specimens before deformation were 115 ÷ 127.6 HV (the arithmetic mean was 122.1 HV) [17]. The measurements of microhardness were taken with a MATSUZAWA MMT-X3 Vickers hardness tester at load of 100g, the measuring accuracy of which was compliant with ASTM E-384.

The experimental part of the investigations of hydromechanical bulge forming of axisymmetric components was conducted at a stand which included the following [4, 5, 17, 19]:

- a tool for hydromechanical bulging of connections equipped with replaceable die inserts (**Figure 3**),
- ZD100 testing machine modified by LABORTECH firm, 1 MN force (the machine is compliant with metrological requirements for Class 1 and was calibrated acc. PN-EN ISO 7500-1:2005) [20],
- 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.

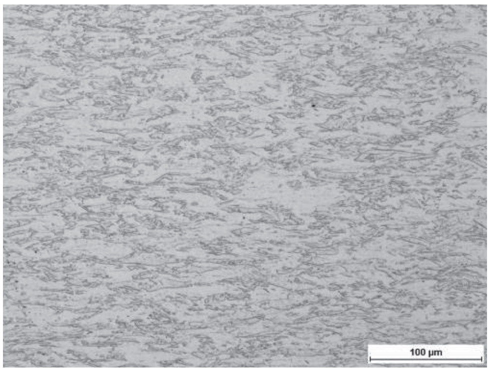

Figure 2 The microstructure of sample of copper

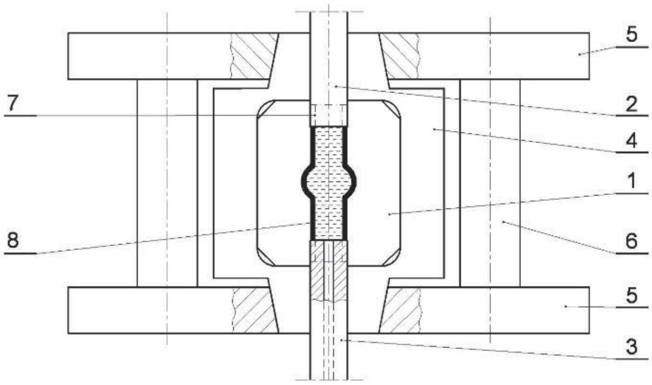

Figure 3 Diagram of the main part of the hydromechanical bulge forming tool, where: 1- die insert, 2- upper punch, 3- lower punch, 4- half-die, 5- pressure platens, 6- guide-posts, 7- tube segment, 8- hydromechanically bulged axisymmetric component

The measurements of wall thickness in longitudinal sections of hydromechanically bulged axisymmetric components were taken with coordinate measuring machine Prismo-Navigator by Zeiss OKM Jena company, the measuring accuracy of which was up to 1 µm [5].

3. RESULTS AND ANALYSIS

Admissible changes of liquid pressure and axial loading were defined as part of the experimentation with hydromechanical bulge forming. For an established course of pressure and upsetting force, a series of axisymmetric components with initial relative wall thickness s_0 / D = 0.045 was formed, which can be seen in **Figure 4**. They were hydromechanically bulged with different displacements of punch Δl = 6 mm; Δl = 8 mm; Δl = 10 mm and Δl = 12 mm were hydromechanically bulged, which corresponded to relative ratios: $\Delta l / l_0$ = 0.054; $\Delta l / l_0$ = 0.073; $\Delta l / l_0$ = 0.091 and $\Delta l / l_0$ = 0.109. Hydromechanically bulged axisymmetric components were formed with a similar pressure change (55 MPa), except for specimens at $\Delta l / l_0$ = 0.054 (50 MPa). For a component at $\Delta l / l_0$ = 0.054; pressure changes greater than those shown in the pressure path (**Figure 4**) resulted in bursting of the spherical cup. A comparison of changes in axial forces in hydromechanical bulge forming of axisymmetric components with the same initial relative thickness s_0 / D = 0.045, for different $\Delta l / l_0$, implies the axial force increases as $\Delta l / l_0$ rises (**Figure 4**). The relative increase in the force for the specimens at $\Delta l / l_0$ = 0.054 and $\Delta l / l_0$ = 0.109 was 67 %. For the specified changes of pressure (**Figure 4**) and relative ratios $\Delta l / l_0$ = 0.073 ÷ 0.109, an exact representation of die-cavities with cup diameter d_1 = 30 mm was obtained. Specimens with that diameter were produced for relative ratios h / d_1 = 0.67 and d_1 / D = 1.36 (where h is height and d_1 is diameter of the spherical cup). Shapes and dimensions of axisymmetric component are shown in **Figure 5**. For the specimens of axisymmetric components at relative ratio Δl / l_0 = 0.054, it was not possible to obtain an exact representation of die-cavities because of an insufficient displacement of punch Δl = 6 mm as part of the hydromechanical bulge forming process.

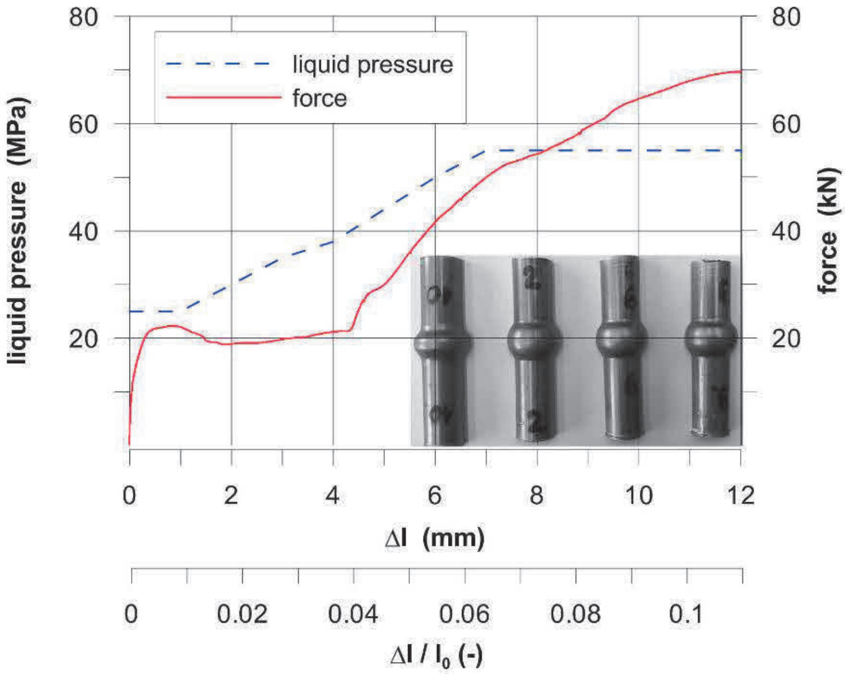

Figure 4 Liquid pressure vs. displacement and force vs. displacement obtained for hydromechanically bulged axisymmetric components at different ratios Δl / l_0 (Δl / l_0 0.054; Δl / l_0 = 0.073; Δl / l_0 = 0.091 and Δl / l_0 = 0.109)

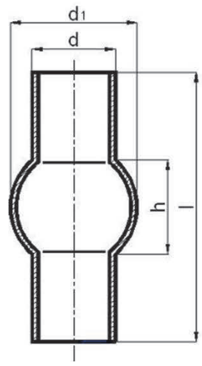

Figure 5 Shapes and dimensions of axisymmetric component

The analysis of wall thickness distribution in longitudinal sections was conducted for hydromechanically bulged axisymmetric components at different ratios Δl / l_0 (Δl / l_0 = 0.054; Δl / l_0 = 0.073; Δl / l_0 = 0.091 and Δl / l_0 = 0.109. Exemplary distributions, together with the spacing of the measurement points are presented in **Figure 6**. Measured thicknesses s were referred to the initial thickness s_0 by means of the relative ratio s / s_0. The analysis of the distribution of wall thicknesses of hydromechanically bulged axisymmetric components made from copper tubes indicates that the character of changes is similar. The wall thickness in the cylindrical part of the axisymmetric components (measurement points 2 ÷ 4 and 9 ÷ 12 shown in **Figure 6**) does not change (for hydromechanically bulged components at Δl / l_0 = 0.054 and Δl / l_0 = 0.091) or the wall is slightly thickened by max. 5 % (at Δl / l_0 = 0.073 and Δl / l_0 = 0.109). In the zone of the cylindrical part transition into the bulged area (measurement points 5 and 9), the wall is maximum thickened for all specimens. It was greatest for hydromechanically bulged components at Δl / l_0 = 0.091 i Δl / l_0 = 0.109 and amounted to 20 %. The maximum thinning is found in the spherical cup (measurement points 6 ÷ 8) and amounts to approx. 10 ÷ 20 % for all specimens.

Changes in the distribution of wall thicknesses in longitudinal sections of hydromechanically bulged copper axisymmetric components obtained in experimental investigation at Δl / l_0 = 0.054 ratio, were similar in character to variations of wall thickness of P265TR1 steel component with the same ratio Δl / l_0 [5]. The material for experimental investigations of steel samples were precision seamless steel tubes obtained during cold drawing [21] at relative thickness s_0 / D = 0.045.

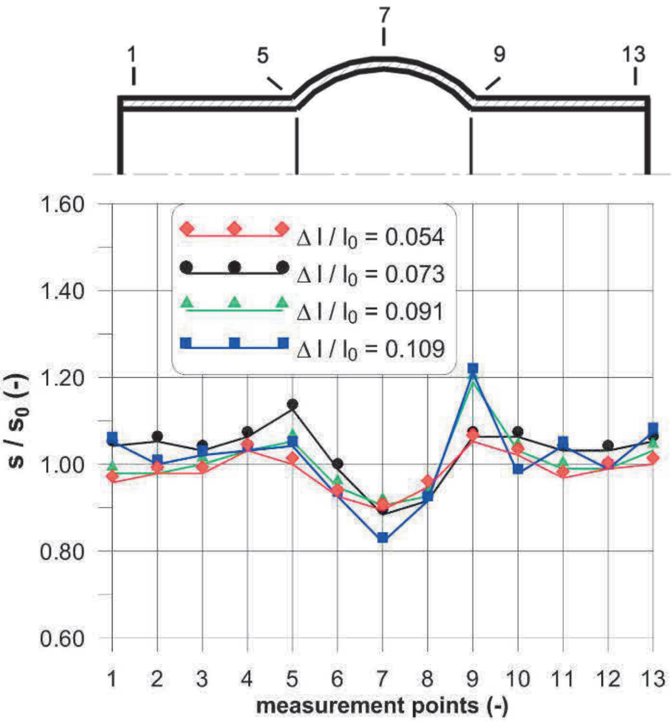

Figure 6 The wall thickness distribution in longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratio s_0 / D = 0.045 and upsetting ratios $\Delta l / l_0$ = 0.054; $\Delta l / l_0$ = 0.073; $\Delta l / l_0$ = 0.091 and $\Delta l / l_0$ = 0.109.

The greatest wall thickening occurred on the radii of body transition to the spherical cup but the wall thickening of copper component was greater than the values obtained for steel element. The wall thinning was found to appear in the caps (no significant differences were found while analyzing the results for copper and steel). The wall thickness in the cylindrical part of the axisymmetric components was compared with the initial thickness of the tube s_0.

4. CONCLUSIONS

The following conclusions were drawn from investigations into hydromechanical bulge forming of copper axisymmetric components with relative initial tube thickness s_0 / D = 0.045 at different upsetting ratios $\Delta l / l_0$ = 0.054; $\Delta l / l_0$ = 0.073; $\Delta l / l_0$ = 0.091 and $\Delta l / l_0$ = 0.109:

1) A comparison of changes in axial forces in hydromechanical bulge forming of axisymmetric components with the same initial relative thickness s_0 / D = 0.045, for different $\Delta l / l_0$, implies the axial force increases as $\Delta l / l_0$ rises. The components were formed with a similar pressure change (55 MPa). The relative increase in the force for the specimens at $\Delta l / l_0$ = 0.054 and $\Delta l / l_0$ = 0.109 was 67 % [5, 17, 19].
2) Changes in the wall thickness distribution in longitudinal sections of hydromechanically bulged copper axisymmetric components with different degree of deformation $\Delta l / l_0$ = 0.054 ÷ 0.109 were similar in character. The greatest wall thickening occurred on the radii of body transition to the spherical cup. The wall thinning was found to appear in the caps. The wall thickness in the cylindrical part of the axisymmetric components was compared with the initial thickness of the tube s_0. The maximum thickening and thinning of the wall were found in the samples with the greatest $\Delta l / l_0$ = 0.109.

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