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THE EFFECT OF UPSETTING RATIO ON MECHANICAL PROPERTIES FOR HYDROMECHANICALLY BULGED AXISYMMETRIC COMPONENTS MADE FROM COPPER TUBES

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The paper presents experimental results of investigations of hydromechanical bulge forming of copper axisymmetric components whose relative wall thickness was s_0/D = 0,045. The deformation ratio of material in the paper was defined as relative upsetting ratio Dl/l_0 (where Dl – the punch displacement, l_0 – initial length of tube). The investigations produced a liquid pressure and a force profile in hydromechanical bulge forming of copper axisymmetric components with different relative ratios Dl/l_0 = 0,054 ÷ 0,109. The research aimed to determine the impact of upsetting ratio on mechanical properties for hydromechanically bulged axisymmetric components. The tensile strength R_m increased and the percentage reduction of area Z decreased as the upsetting ratio Dl/l_0 increased.

Key words: hydromechanical bulge forming, upsetting ratio, axisymmetric components, copper tubes, mechanical properties

INTRODUCTION

The hydromechanical bulge forming is a hydroforming technique that appears to be an interesting method for manufacturing of pipe connections, including T-pipes, Y-shapes (3-way connectors with an angled branch), X-shapes (cross-joints) and axisymmetric components [1,2]. Copper pipe connections are used in hydraulic, heating, gas and waste water systems. The process is a type of liquid pressure forming, in which an 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 [1]. 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, a quick joining procedure, and an easy implementation [3].

The investigations conducted for many years by J. Chałupczak et al. [1,4,5] 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. 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 [6-11].

The paper presents experimental results for hydromechanical bulging of copper axisymmetric components whose relative wall thickness was s_0/D = 0,045. The investigations aimed to determine impact of the degree of deformation on tensile strength R_m and percentage reduction of area Z for hydromechanically bulged axisymmetric components made from copper tubes. The degree of deformation of material was defined as the relative upsetting ratio Dl/l_0 [1,4,5,12] (where Dl – the punch displacement, l_0 – initial length of tube).

METHODOLOGY

The material for experimental investigations included 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

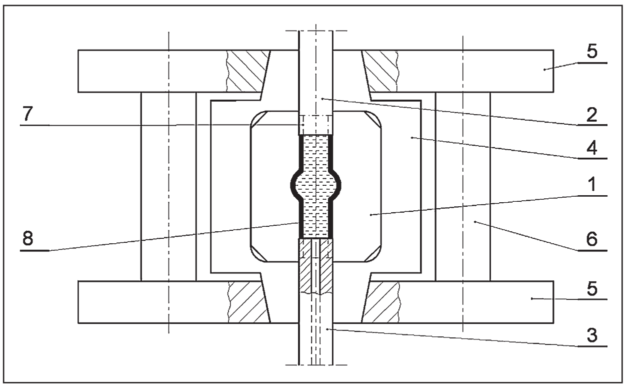

Figure 1 Diagram of the main part of the hydromechanical bulge forming tool, where: 1- die insert, 2 - upper punch, 3 - lower punch, 4 - half-die, 5 - pressure platens, 6 - guide-posts, 7 - tube segment, 8 - hydromechanically bulged axisymmetric component.

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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. Additionally, copper pipe connections are used in hydraulic, heating, gas and waste water systems [2,12]. The mechanical properties of copper tubes were determined by static tensile testing (R_m = 268 MPa, A = 29,7 %) [12]. The experimental part of the research was conducted at a special stand which included the following:

- A tool for hydromechanical bulging of connections equipped with replaceable die inserts (Figure 1),
- ZD100 testing machine modified by LABORTECH, 1 MN force (the machine is compliant with metrological requirements for Class 1 and was calibrated as per PN-EN ISO 7500-1:2005),
- A hydraulic feeding system, the most important component of which was a hand-operated pump boosting pressure 0 ÷ 150 MPa,
- A computer stand with Test&Motion software (LABORTECH) to measure forces and displacements.

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 2. They were hydromechanically bulged with different displacements of punch Dl = 6 mm; Dl = 8 mm; Dl = 10 mm and Dl = 12 mm were hydromechanically bulged, which corresponded to relative ratios: Dl/l_0 = 0,054; Dl/l_0 = 0,073; Dl/l_0 = 0,091 and Dl/l_0 = 0,109. Hydromechanically bulged axisymmetric components were formed with a similar pressure change (55 MPa), except for specimens at Dl/l_0 = 0,054 (50 MPa). For a component at Dl/l_0 = 0,054; pressure changes greater than those shown in the pressure path (Figure 2) resulted in bursting of the spherical cup.

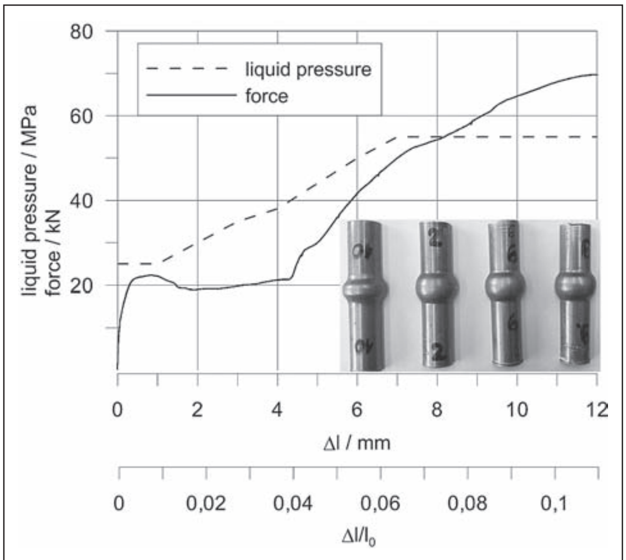

Figure 2 Liquid pressure vs. displacement and force vs. displacement obtained for hydromechanically bulged axisymmetric components at different upsetting ratios Dl/l_0.

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 Dl/l_0, implies the axial force increases as Dl/l_0 rises (Figure 2). The relative increase in the force for the specimens at Dl/l_0 = 0,054 and Dl/l_0 = 0,109 was 67 % .

For the specified changes of pressure (Figure 2) and relative ratios Dl/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). For the specimens of axisymmetric components at relative ratio Dl/l_0 = 0,054, it was not possible to obtain an exact representation of die-cavities because of an insufficient displacement of punch Dl = 6 mm as part of the hydromechanical bulge forming process.

Mechanical properties of longitudinal sections of hydromechanically bulged axisymmetric components were determined by static tensile testing. They were defined by tensile strength R_m and percentage reduction of area Z. The effect of upsetting ratio on tensile strength R_m obtained for hydromechanically bulged axisymmetric components made from copper tubes at s_0/D = 0,045 is shown in Figure 3.

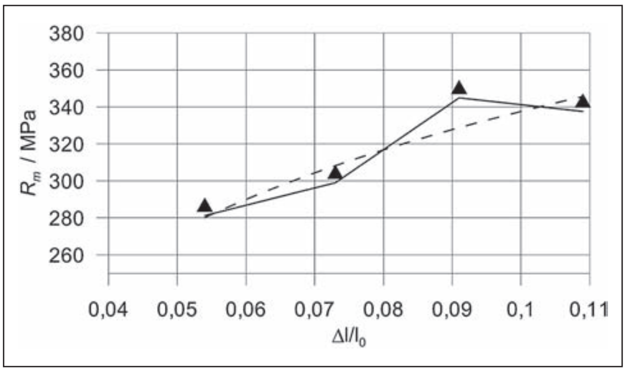

Figure 3 The effect of upsetting ratio on tensile strength R_m obtained for hydromechanically bulged axisymmetric components made from copper tubes at s_0/D = 0,045.

The data shown in Figure 3 suggest that the upsetting ratios Dl/l_0 have a considerable influence on the values of tensile strength R_m calculated on the basis of the static tensile test. As can be seen from Figure 3, an increase in the upsetting ratio Dl/l_0 from 0,054 to 0,109 causes an increment in the tensile strength R_m of hydromechanically bulged axisymmetric components. The values of R_m obtained for ratios Dl/l_0 = 0,054; Dl/l_0 = 0,073; Dl/l_0 = 0,091 and Dl/l_0 = 0,109 were: 281,25

MPa; 299,02 MPa; 344,9 MPa and 337,60 MPa, respectively. The relative increase in the tensile strength R_m for the specimens at $Dl/l_0 = 0{,}054$ and $Dl/l_0 = 0{,}091$ was approx. 22 % . The difference between the value of the tensile strength R_m for material before deformation (268 MPa) and hydromechanically bulged axisymmetric component at $Dl/l_0 = 0{,}091$ (344,9 MPa) amounts to approx. 29 %. The Figure 3 also shows a curve obtained by an approximation carried out with the function $R_m = 93{,}21 \ln (Dl/l_0) + 552{,}2$.

The effect of upsetting ratio on the percentage reduction of area *Z* obtained for hydromechanically bulged axisymmetric components made from copper tubes at $s_0/D = 0{,}045$ is presented in Figure 4.

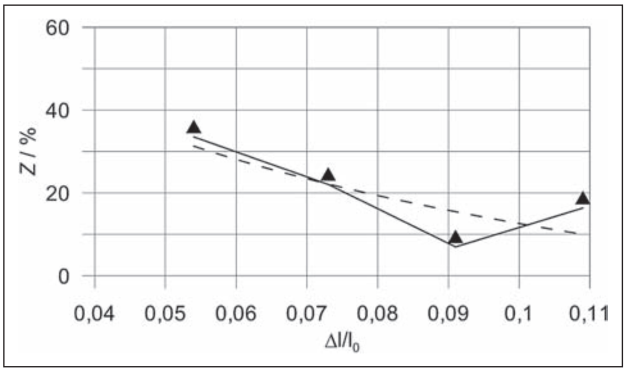

Figure 4 The effect of upsetting ratio on the percentage reduction of area *Z* obtained for hydromechanically bulged axisymmetric components made from copper tubes at $s_0/D = 0{,}045$.

The values of *Z* obtained for ratios $Dl/l_0 = 0{,}054$; $Dl/l_0 = 0{,}073$; $Dl/l_0 = 0{,}091$ and $Dl/l_0 = 0{,}109$ were 33,54 %; 22,07 %; 7 % and 16,37 %, respectively. The percentage reduction of area Z decreased as the upsetting ratio Dl/l_0 rose. Figure 4 also shows a curve obtained by approximating the function $Z = - 30{,}29 \ln (Dl/l_0) - 57{,}12$.

The results indicate that change of mechanical properties (increase of tensile strength R_m and decrease of the percentage reduction of area *Z*) in hydromechanically bulged axisymmetric components made from copper tubes is related to strain hardening of material after cold deformation.

CONCLUSION

The following conclusions were drawn from the investigations into hydromechanical bulge forming of copper axisymmertic components with relative initial tube thickness $s_0/D = 0{,}045$ at different upsetting ratios $Dl/l_0 = 0{,}054$; $Dl/l_0 = 0{,}073$; $Dl/l_0 = 0{,}091$ and $Dl/l_0 = 0{,}109$:

1. The results indicate the possibility of hydromechanical bulge forming of axisymmetric components from copper tubes at $s_0/D = 0{,}045$, using established patterns of liquid pressure and upsetting force. It was confirmed by successful tests at specimen relative displacement of up to $Dl/l_0 = 0{,}109$.
2. For specified pressure patterns and changes and relative ratios $Dl/l_0 = 0{,}073 \div 0{,}109$, an exact representation of die-cavities with diameter of cup $d_1 = 30$mm was obtained (which corresponded to relative ratios $h/d_1 = 0{,}67$ and $d_1/D = 1{,}36$).
3. Both the axial force and the tensile strength R_m increased the upsetting ratio Dl/l_0 for hydromechanically bulged components rose with a the similar pressure change (55 MPa). The percentage reduction of area Z decreased as the upsetting ratio Dl/l_0 rose.

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Note: The professional translator for the English language is Jacek Spólny, TP/6122/05, Poland.