INFLUENCE OF THE UPSETTING RATIO ON MICROHARDNESS IN HYDROMECHANICALLY BULGED AXISYMMETRIC COMPONENTS MADE FROM COPPER TUBES

MIŁEK Tomasz

Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering, Department of Applied Computer Science and Armament Engineering, Kielce, Poland, EU, tmatm@tu.kielce.pl

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 specimens used in investigations were segments of copper tubes having the outer diameter D= 22 mm and wall thickness $s_0 = 1$ mm. In the paper, the deformation ratio of material was defined as the relative upsetting ratio $\Delta l/l_0$ (where Δl - the punch displacement, l_0 - the initial length of tube). The investigations aimed to determine the impact of the upsetting ratio on microhardness in different zones of hydromechanically bulged axisymmetric components. The measurements of microhardness were taken with the *Matsuzawa* Seiki Co. MMT-X3 *Vickers micro-hardness tester*. The paper gives the comparison of the microhardness distributions in longitudinal sections of hydromechanically bulged copper axisymmetric components with different relative ratios $\Delta l/l_0=0.054 \div 0.109$.

Keywords: Hydromechanical bulge forming, hydroforming, axisymmetric components, microhardness

1. INTRODUCTION

Hydromechanical bulge forming is mainly applied to the serial production of pipe connections, including T-pipes [1-3], Y-shapes [4], X-shapes [1, 5] and axisymmetric components [6-8]. The process is a type of hydroforming [2, 3], in which the external upsetting force is additionally applied. The concept of hydroforming has a wider significance and also includes the processes of material forming by liquid pressure without an external upsetting force. The hydromechanical bulge forming process 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]. In addition to the liquid pressure, the upsetting force is also responsible for hydromechanical bulge forming. It causes the material flow in the radial direction, thus making it possible to obtain greater bulging coefficient $k=d_1/D$ (where: d_1- the largest diameter of the cup, D - the initial external tube diameter). Experimentally obtained value of ratio (k=1.36) [8] is higher than the maximum admissible coefficient presented by Limb [6] for bulging pressure of the liquid in copper tube forming (k=1.33).

In Poland, the method of hydromechanical bulging of T-pipes was patented by Chałupczak in 1973 [9]. The experimental investigations conducted for many years by Chałupczak et al. [1, 4, 5, 7] have demonstrated that the method makes it possible to manufacture T-pipes of all steel grades 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 hydroforming of reducing and equal pipe connections, including T-pipes, Y-shapes, X-shapes made from different materials have continued. Some studies on this process have been reported [10 - 18]. They have been both experimental and computer modelling investigations. The analysis of these papers shows good compatibility between the results of numerical simulation and experimental data. Ray and Mac Donald [10] formed X- and T- branch components using a tube hydroforming machine and compared the results with FEA simulations (LS-DYNA3D). Experimental investigations, 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. [11]. 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 also clamping and axial forces were studied [12]. Przybylski et al. [13] described the influence of design characteristics and manufacturing process parameters on the strength of tubular aluminium joints produced by hydroforming. Nikhare et al. [14] conducted experimental and numerical analysis of low pressure hydroforming for 409 stainless steel tubes. That was found to reduce the internal fluid pressure and die closing force in the production of hydroformed part without buckling. Stadnik et al [15] described FEM simulations (ABAQUS) and experiments on 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 et al. [16] demonstrated that the control of wrinkling for the tube hydroforming is effective in improving the formability. Ceretti et al. [17] described the experiments and the analytical model of tube bulge test for the identification of the flow stress under a biaxial stress state. Its innovative aspect was that the tube ends were blocked and the stress state was derived from flow rule and volume constancy [17]. Experiments were conducted on seamless (copper) and welded (aluminized steel) tubes, using equipment available at the University of Brescia laboratories. In her paper [18], Sadłowska discussed the application of modified forming limit diagram (FLD) for hydroforming of X-shapes from copper tubes. Joo et al. [19] demonstrated that a flanged automotive part can be formed using the hydroforming process without additional stages such as bending and pre-forming. The investigations into hydroforming involved the use of HF440 steel tubes with the outside diameter of 65mm and wall thickness of 2mm. In the study, Joo analyzed hydroforming characteristics at various pressure conditions and compared experimental results with the finite element simulation results (DYNAFORM).

The paper presents experimental results on hydromechanical bulging of copper axisymmetric components, whose relative wall thickness was $s_0/D= 0.045$. The investigations aimed to determine the impact of the degree of deformation on microhardness for hydromechanically bulged axisymmetric components made from copper tubes. The degree of deformation of material was defined as the relative upsetting ratio $\Delta l/l_0$ (where Δl - the punch displacement, l_0 - initial length of tube) [1, 20].

2. METHODOLOGY

The material for experimental investigations were copper (Cu99,E) tube segments (from seamless tubes), whose outer diameter was D=22mm and the wall thickness s_0=1mm (which corresponded to the relative thickness $s_0/D= 0.045$). The initial lengths of tube segments were l_0=110mm. In these investigations, pure copper was selected as the testing material due to its excellent formability and a wide range of applications in industries. Additionally, copper pipe connections are used in hydraulic, heating, gas and waste water systems. The mechanical properties of copper tubes were determined by static tensile testing (R_m=268MPa, A=29.7%). The experimental part of the investigations 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 firm, 1MN force (the machine is compliant with metrological requirements for Class 1 and was calibrated acc. PN-EN ISO 7500-1:2005),
- 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.

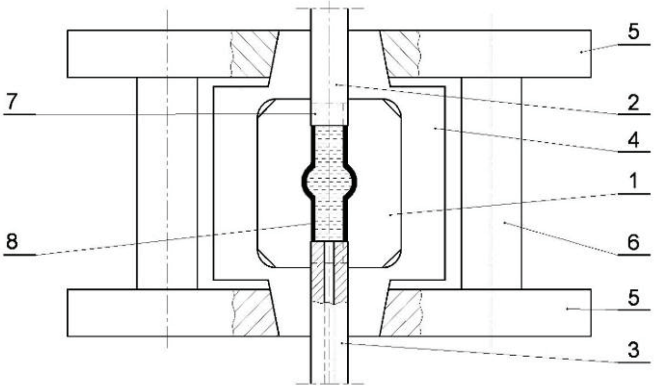

Figure 1 Diagram of the main part of the hydromechanical bulge forming tool, where: 1- die insert, 2- upper punch, 3- lower punch, 4- half-die, 5- pressure platens, 6- guide-posts, 7- tube segment, 8- hydromechanically bulged axisymmetric component

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 measurements were performed in accordance with literature recommendations [21].

3. RESULTS AND ANALYSIS

In the experimental investigations, axisymmetric components with initial relative wall thickness $s_0/D=0.045$ and different displacements of punch $\Delta l=6mm$; $\Delta l=8mm$; $\Delta l=10mm$ and $\Delta l=12mm$ 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 (55MPa), except for specimens at $\Delta l/l_0=0.054$ (50MPa), which can be seen in **Figure 2a**. For component at $\Delta l/l_0=0.054$, pressure changes greater than the ones shown in the pressure path resulted in the burst of the spherical cup. In bulging, force waveforms as the function of displacement were obtained (**Figure 2b**).

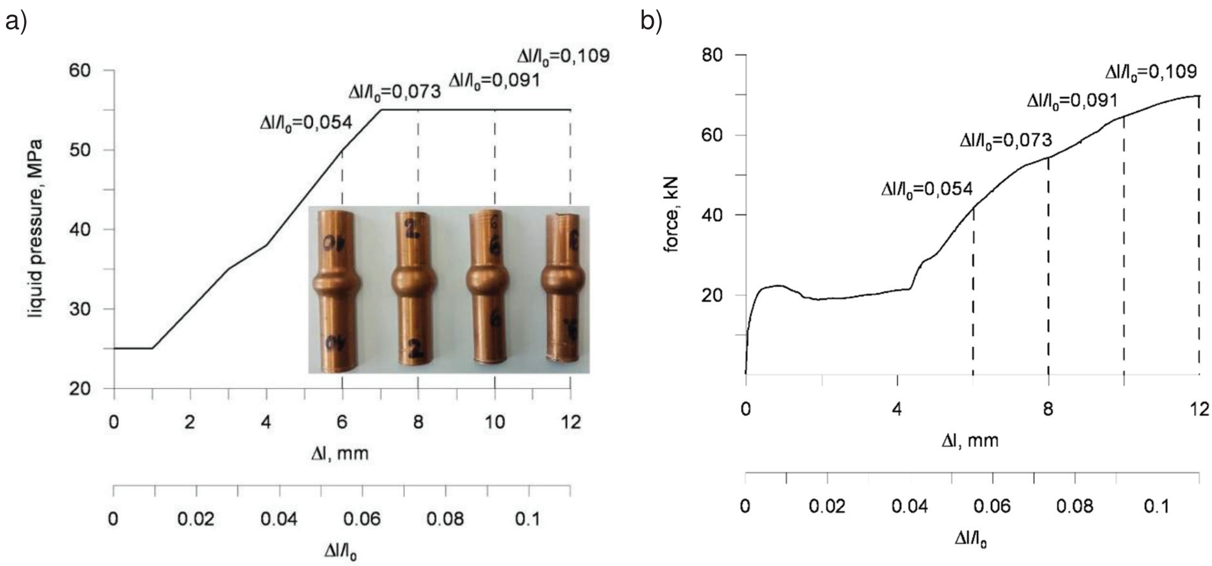

Figure 2 Liquid pressure vs. displacement (a) and force vs. displacement obtained for hydromechanically bulged axisymmetric components at different ratios $\Delta l/l_0$ ($\Delta l/l_0=0.054$; $\Delta l/l_0=0.073$; $\Delta l/l_0=0.091$ and $\Delta l/l_0=0.109$)

On the basis of 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 $\Delta l/l_0$, it can be stated that the axial force increases with an increase in $\Delta l/l_0$ (**Figure 2b**). The maximum values obtained for ratios $\Delta l/l_0=0.054$; $\Delta l/l_0=0.073$; $\Delta l/l_0=0.091$ and $\Delta l/l_0=0.109$ were 41.69kN; 54.34kN; 64.63kN and 69.66kN, respectively. 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%. It should be noted that experimentally obtained patterns of pressure start at certain initial values, which allowed initial bulging of a tube segment. That was necessary to make pits in pipes faces with the punch conical protrusion so that the pipes could be sealed.

For the specified pressure patters and changes (**Figure 2a**) and relative ratios $\Delta l/l_0=0.073\div0.109$, an exact representation of die-cavities with diameter of cup $d_1=30$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 $\Delta l/l_0=0.054$, it was not possible to obtain an exact representation of die-cavities because of too small displacement of punch $\Delta l=6$mm during hydromechanical bulge forming process.

The analysis of microhardness distributions in different zones of longitudinal sections was conducted for hydromechanically bulged axisymmetric components made from copper tubes at different $\Delta l/l_0$ ratios ($\Delta l/l_0=0.054$; $\Delta l/l_0=0.073$; $\Delta l/l_0=0.091$ and $\Delta l/l_0=0.109$. **Figure 3** presents the spacing of measurement zones for microhardness measurements. **Figure 4** shows exemplary identations in longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratio $s_0/D=0.045$ after a Vickers hardness test.

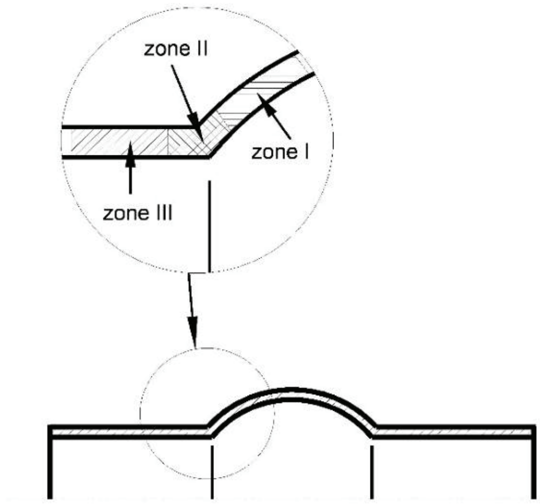

Figure 3 Spacing of measurement zones for microhardness measurements in longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratio $s_0/D=0.045$

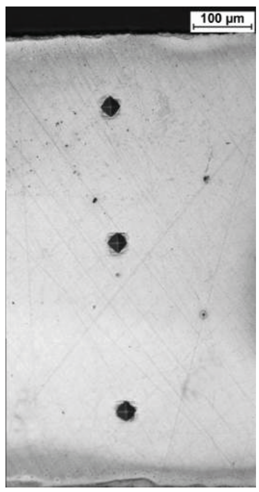

Figure 4 Identations for microhardness measurements in zone III of longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratios $s_0/D=0.045$ and $\Delta l/l_0= 0.109$

Each specimen was measured in three zones, measurements were repeated three times and the arithmetic mean was computed. The microhardness measurements did not demonstrate relevant differences. The results obtained on the basis of arithmetic values of measurements in different zones of longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratios $\Delta l/l_0=0.054$; $\Delta l/l_0=0.073$; $\Delta l/l_0=0.091$ and $\Delta l/l_0=0.109$ are presented in **Figure 5** in the form of points.

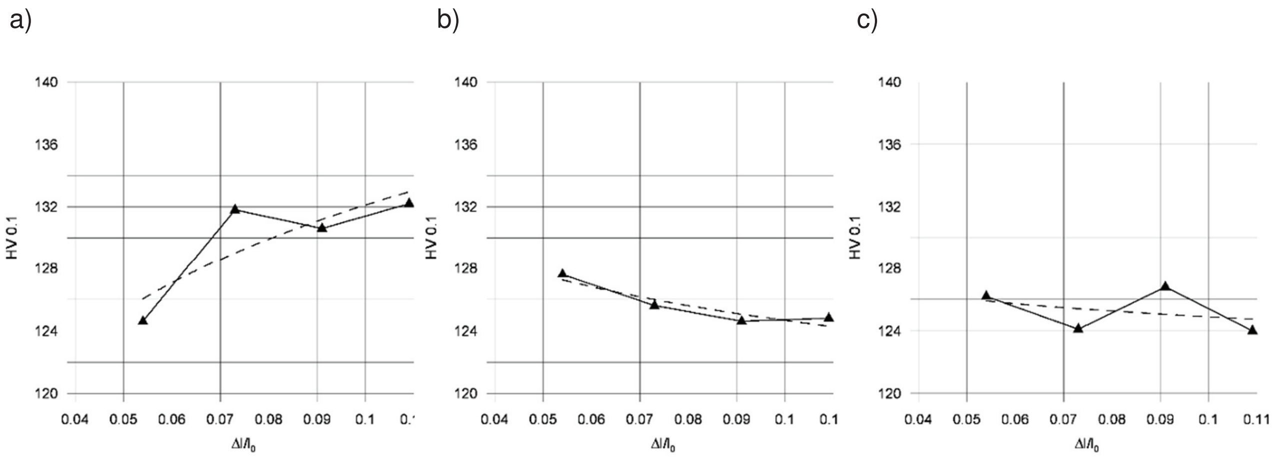

Figure 5 The microhardness distributions in different zones of longitudinal sections of hydromechanically bulged axisymmetric components made from copper tubes at relative ratios $\Delta l/l_0$=0.054; $\Delta l/l_0$=0.073; $\Delta l/l_0$=0.091 and $\Delta l/l_0$=0.109: a) zone I, b) zone II, c) zone III

The microhardness values of specimens before deformation were 115÷127.6 HV (the arithmetic mean was 122.1 HV). The analysis of the results of the microhardness distributions (**Figure 5**) indicates small increase in the values of microhardness in the three zones of longitudinal sections of hydromechanically bulged axisymmetric components when compared with the microhardness of the material before deformation. The greater values of microhardness occurred in zone I (**Figure 5a**) for components at relative ratios: $\Delta l/l_0$=0.073; $\Delta l/l_0$=0.091 and $\Delta l/l_0$=0.109. In this zone, microhardness increased with an increase in the upsetting ratio $\Delta l/l_0$. The maximum value of microhardness for axisymmetric component at $\Delta l/l_0$=0.109 amounted to 132.2HV and was approx. 8% higher than the value for the tube before deformation. The evaluation of microhardness distributions was also made for other zones (zones II and III in **Figure 5 b** and **Figure 5c,** respectively**)**. The comparison of microhardness in zones I and II indicates that despite increased upsetting ratio $\Delta l/l_0$, the character of changes in microhardness of the components is very similar. Microhardness measured in the cylindrical part of axisymmetric components (zone III - **Figure 5c**) was compared with values obtained on the radii of body transition to the cap (zone II - **Figure 5b**), but no substantial differences were found.

4. CONCLUSIONS

On the basis of investigations carried out into hydromechanical bulge forming of axisymmetric components made from copper tubes with relative 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, it can be stated as follows:

1) It is possible to conduct hydromechanical bulge forming of axisymmetric components from copper tubes at s_0/D=0.045. It was confirmed by successfully performed tests at specimen relative displacement up to $\Delta l/l_0$=0.109.
2) The axial force increased with an increase in the upsetting ratio $\Delta l/l_0$ at the similar pressure change (55MPa). 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%.
3) The microhardness increased with an increase in the upsetting ratio $\Delta l/l_0$ only in zone of caps of longitudinal sections of hydromechanically bulged axisymmetric components. In other areas (cylindrical part of component and zone of the radii of body transition to the cap), no substantial differences were found.

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