Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

The wall thickness distributions in longitudinal sections hydromechanically bulged axisymmetric components made from copper and steel tubes

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Received 16.04.2014; published in revised form 01.07.2014

ABSTRACT

Purpose: The paper presents experimental results that concern hydromechanical bulging of copper and P265TR1 steel axisymmetric component whose relative wall thickness was $s_0/D=0.04$ (where s_0 is the wall thickness and D is outer diameter of tube segments).

Design/methodology/approach: 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. The technology involves placing a tube segment in a die-cavity, pouring some liquid over it, and sealing the faces.

Findings: The experimental investigations, described in the paper, on hydromechanical bulge forming of copper and P265TR1 steel axisymmetric component with the ratio $h/d_1=0.67$ (where h is height and d_1 is diameter of spherical cup) aimed to compare the wall thickness distribution in longitudinal sections of axisymmetric components. Besides it, the aim of experimental inwestigations was to compare patterns of pressure changes and force at relative displacement up to $\Delta l/l_0=0.06$.

Research limitations/implications: 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.

Originality/value: The experimental investigations, described in the paper aimed to determine the possibility of hydromechanical bulge forming of axisymmetric components made from copper and steel tubes, compare force waveforms at the constant upsetting ratio, compare distribution of wall thickness.

Keywords: Hydromechanical bulge forming; Hydroforming; Axisymmetric component; The wall thickness distribution

Reference to this paper should be given in the following way:

T. Miłek, The wall thickness distributions in longitudinal sections hydromechanically bulged axisymmetric components made from copper and steel tubes, Journal of Achievements in Materials and Manufacturing Engineering 65/1 (2014) 20-25.

PROPERTIES

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 [1,2]. In most publications the process of hydromechanical bulge forming is called hydroforming process [3,4] but the concept of hydroforming has wider significance and includes the processes of material forming by liquid pressure without an external upsetting force, too. In recent years, with the reduction of cycle time and process control improvements, the field of applications of hydroforming has grown considerably. The process is employed while manufacturing pipe connections, including axisymmetric components [2,4]. Steel pipe connections are used in power, chemical, machine building, bicycle and automotive industries. In hydraulic, heating, gas and waste water systems, copper pipe connections are used [3-6].

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 (where h is height and d_1 is diameter of spherical cup). The basic parameters of the hydromechanical process of bulge forming are: liquid pressure and axial loading.

The investigations conducted for many years by J. Chalupczak et al. [1,2,5,6] 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 pipe connections have continued. Some studies on the process of hydroforming have been reported [7-14]. They have been both experimental and computer modeling investigations. Hydromechanical of bulge forming is being employed for years, but the technology of hydroforming has not been investigated completely, so far.

The experimental investigations, described in the paper, on hydromechanical bulge forming of axisymmetric components made from copper and steel tubes with relative wall thicknesses $s_0/D=0.04$ and different ratio $h/d_1=0.67$ and 0.72 aimed to:

- determine the possibility of hydromechanical bulge forming of axisymmetric components made from copper and steel tubes,
- compare force waveforms at the constant upsetting ratio and the same change in pressure,
- compare distribution of wall thickness in longitudinal sections of axisymmetric components made from copper and steel tubes.

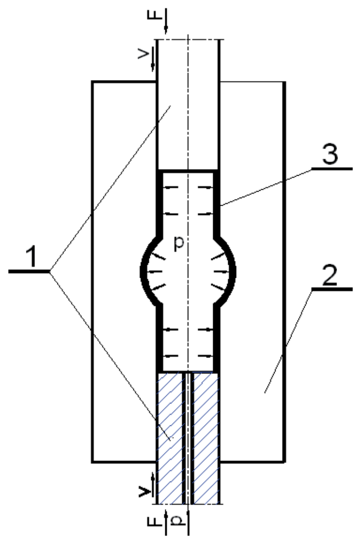

Fig. 1. Hydromechanical bulge forming of axisymmetric component, where: 1 – punches, 2 – die, 3 – component

2. Methodology

The material for experimental investigations were copper (Cu99,E) and P265TR1 tube segments, whose outer diameter was D=22 mm and the wall thickness s_0=1 mm, (which corresponded to the relative thickness $s_0/D=0.04$). The initial lengths of tube segments were 120 mm. The mechanical properties of copper tubes used in the experiment are presented in Table 1. They were determined by static tensile testing. Table 1 also shows the mechanical properties for P265TR1 steel (PN-EN 10216-1 2002).

Table 1.
Mechanical properties of copper [5] and P265TR1 steel tubes (PN-EN 10216-1 2002)

Material	R_m, MPa	R_{eH}, MPa	A, %	$R_{p0.2}$, MPa
copper	268	-	29.7	-
P265TR1 steel	410-570	≤ 265	≤ 21	≤ 235

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,
- ZD100 testing machine modified by LABORTECH firm, 1 MN 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.

The measurements of pressure were taken with pressure transducer NPXG 1000, the range of which was 0-100 MPa. 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 hydro-mechanical bulging of axisymmetric components at the constant upsetting ratio $\Delta l/l_0$=0.06 (which corresponded to displacements of punches: Δl=7.5 mm) and different the bulging coefficient d_1/D=1.36 (where d_1 is the largest diameter of the cup; d_1=30 mm and D is the initial external tube diameter; D=22 mm) and d_1/D=1.45 (where d_1=32 mm and D=22 mm) for copper and P265 steel tubes. Their coefficients h/d_1 were respectively 0.67 and 0.72. Example of experimentally bulged part from copper tube obtained in experimental investigations is presented in Fig. 2.

For the above-mentioned connections, pressure patters and changes in force were compared which is shown in Fig. 3. 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 s_o that the pipes could be sealed. The maximum value of the force for axisymmetric components made from P265 steel tubes amounted to 39.748 kN and was 61% higher than the highest value for connections made from copper tubes (24.682 kN), although the latter were bulged at slightly (maximum approx. 5%) higher pressure.

Fig. 2. Hydromechanically bulged axisymmetric components from copper tubes at ratios s_0/D=0.04 and $\Delta l/l_0$=0.062

The analysis of wall thickness distribution in longitudinal sections was conducted for bulge formed tubes with ratio h/d_1=0.67 (which corresponded to the bulging coefficient d_1/D=1.36) and punch displacement Δl=7.5 mm ($\Delta l/l_0$=0.06). Thickness measurements of test samples did not demonstrate relevant differences. Connections from copper and steel tubes obtained at similar changes in pressure were cut along longitudinal 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 [15]. Exemplary distributions, together with the spacing of the measurement points are presented in Fig. 4.

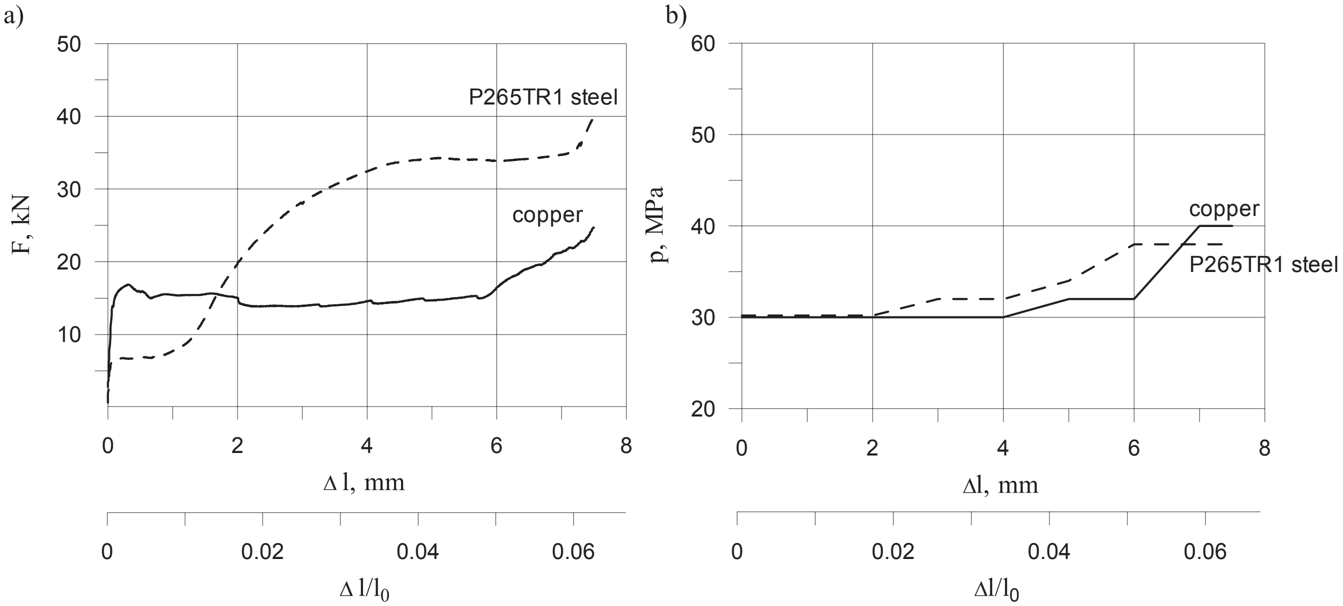

Fig. 3. Force vs. displacement (a) and liquid pressure vs. displacement (b) obtained for hydromechanically bulged axisymmetric components made from copper and P265TR1 steel tubes at ratios $s_0/D=0.04$, $h/d_1=0.72$ and $\Delta l/l_0=0.06$

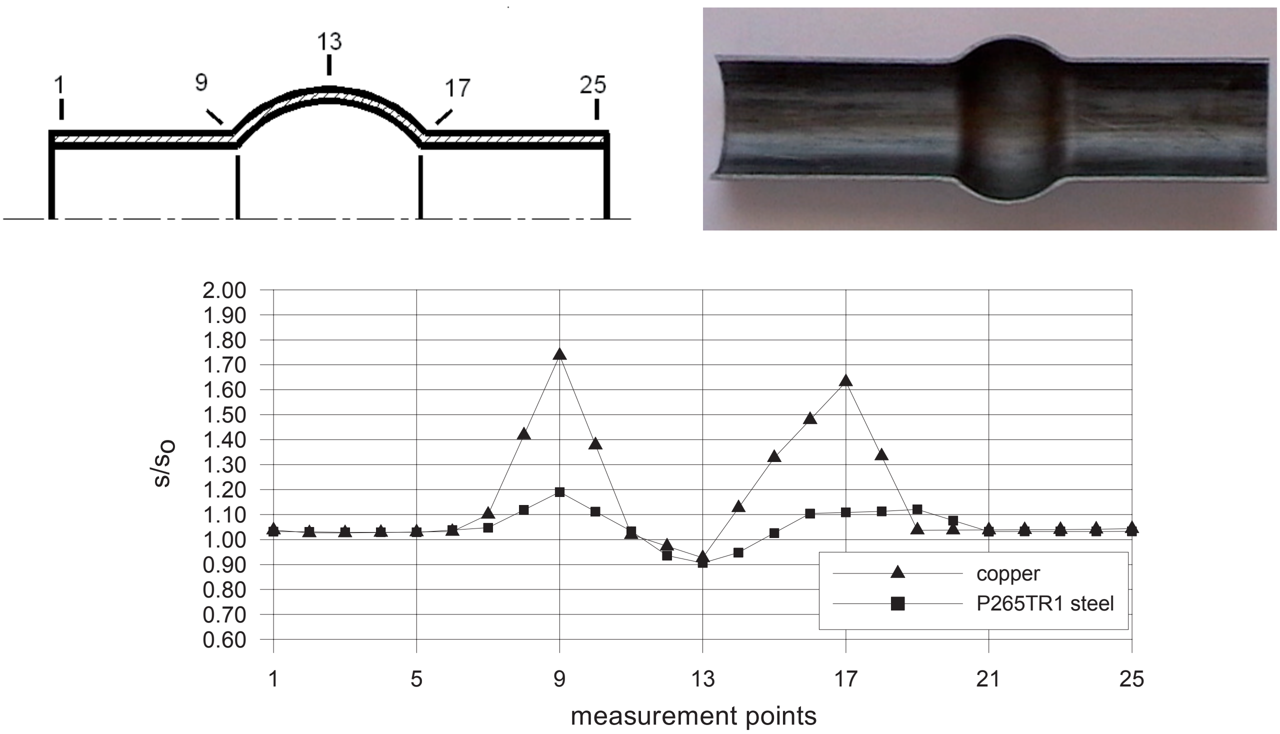

Fig. 4. The wall thickness distribution in longitudinal sections hydromechanically bulged axisymmetric components made from copper and P265TR1 steel tubes at ratios $s_0/D=0.04$, $h/d_1=0.67$ and $\Delta l/l_0=0.06$

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 and P265TR1 steel tubes indicates that the character of changes is similar. The wall thickness in the cylindrical part of the axisymmetric components (measurement points 1-7 and 19-25 shown in Fig. 4) does not change or the wall is slightly thickened by max. 4% for copper and max. 7% for steel. In the zone of the cylindrical part transition into the bulged area (measurement points 9 and 17), the wall is thickened by max. 19% for steel and max. 70% for copper. The maximum thinning is found in the spherical cup (measurement points 11-15) and amounts to approx. 7% for copper and approx. 10% for steel.

4. Conclusions

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

1. The results of the research on hydromechanical bulge forming of copper and steel tubes with a relative wall thickness $s_0/D=0.04$ and ratios $h/d_1=0.67$-0.72 testify that this method is technologically suitable for axisymmetric components. For the specified ranges of liquid pressures and ratio of pipe-component bulging $\Delta l/l_0=0.06$, an exact representation of die was obtained.
2. At the same relative displacements $\Delta l/l_0=0.06$ and ratio $h/d_1=0.72$ (which corresponded to the bulging coefficient $d_1/D=1.45$), axial force of hydromechanical bulge forming for axisymmetric component made from P265TR1 steel tube was greater than the value obtained for bulge forming of component made from copper tube (increase by approx. 61%).
3. Changes in the distribution of wall thicknesses of axisymmetric components made from P265TR1 steel and copper tubes undergoing hydromechanical bulge forming with $\Delta l/l_0=0.06$ and ratio $h/d_1=0.67$ (which corresponded to the bulging coefficient $d_1/D=1.36$) were similar in character. The greatest wall thickening occurred on the radii of body transition to the spherical cup (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.

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