THE ANALYSIS OF PLASTIC FLOW OF LASER WELDED TUBES IN THE PROCESS OF HYDROMECHANICAL FORMING

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ANALÝZA PLASTICKÉHO TOKU LASEROM ZVÁRANÝCH RÚR V PROCESE HYDROMECHANICKÉHO TVÁRNENIA

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Abstrakt

Technológia hydraulického tvárnenia je veľmi známa už niekoľko rokov a zaznamenáva extrémne dynamický rozvoj v automobilových aplikáciách, obzvlášť v Nemecku a Spojených štátoch amerických. Hydraulické tvárnenie dvojíc kovových plechov je ešte v štádiu pred zavedením do priemyslu. Príspevok predstavuje tento proces a poukazuje na určité špecifické výsledky výskumnej práce. Uvedené je základné smerovanie výskumu vzhľadom na transfer procesu hydraulického tvárnenia na dvojice kovových plechov do priemyselného rozsahu. Hydraulické tvárnenie využíva tlak kvapaliny namiesto lisovníka v konvenčnom nástroji na tvarovanie časti do požadovaného tvaru matrice. Postup je veľmi užitočný pre vytváranie celých súčiastok, ktoré by inak museli byť vyrobené viacnásobným lisovaním. Hydraulické tvárnenie ponúka niekoľko výhod v porovnaní s konvenčnou výrobou lisovaním a zváraním, ako je zjednotenie súčiastky, redukcia hmotnosti, zlepšenie konštrukčnej pevnosti a poddajnosti, nižšia cena lisovacej formy, menej sekundárnych operácii, nízke odpruženie a zníženie množstva kovového odpadu. Zvyšujúce sa požiadavky na veľmi komplikované tvary súčiastok ako sú: výfukový systém áut, spojovacie trubice, branch-joins, rámy telesa áut, rámy striech áut, atď., vyžadujú procesy hydraulického tvárnenia zakružovaných rúr. Laboratórne zariadenie pre hydromechanické tvárnenie rúr je navrhnuté a pripravené zohľadniť analýzy laserom zváraných predliskov prebiehajúcich počas skúšky hydraulického hĺbenia rúr vnútorným tlakom kvapaliny. Príspevok uvádza výsledky distribúcie lokálnej deformácie v laserom zváraných rúrach.

Abstract

The hydroforming technology has been well-known for several years and undergoes an extremely dynamic development in automotive applications, especially in Germany and the United States. The hydrofoming of sheet metal pairs is still at a pre-industrial stage. This publication presents the process and draws attention to some particular results of research work. Principal working directions for investigations, regarding the transfer of the hydroforming process for sheet metal pairs on industrial scale have been presented. Hydromechanical forming uses fluid pressure in place of the punch in a conventional tool set to form the part into the desired shape of the die. The technique is very useful for producing complete components that would otherwise be made from multiple stampings joined together. Hydroforming offers several advantages compared with conventional manufacturing by stamping and welding, such as the part consolidation, weight reduction, improved structural strength and stiffness, lower tooling costs, fewer secondary operations, low springback, and reduced the scrap. The increasing demand for highly complex shapes of the elements such as: car exhaust systems, connector pipes, branch-joins, car body frames, car roof frames, etc., require developing hydromechanical processes of tube forming. A laboratory stand for hydromechanical forming of tubes has been designed and prepared taking into account the analysis of laser welded blanks flow during hydraulic bulging tests and the bulging tests of tubes by inner liquid pressure. The paper presents the results of local strain distribution in laser welded tubes.

Key words: laser welded blanks, tubular welded blanks, formability, hydroforming, hydromechanical forming, hydro-bulging, strain analysis

1. Introduction

The process of frictionless forming of stamped elements has been presented and discussed in many papers regarding plastic processing [1-3]. However the majority of them discuss theoretical aspects of the process. It also needs to be emphasised that the mechanical state of process, i.e. stress and strain can change during the process of forming and such changes are mainly local. The changes of mechanical state are caused by forming tools such as matrix, punch, blank holder since their work may vary depending on technological conditions of the process. Therefore technological conditions need to be carefully defined because they can have a considerable impact on the mechanical state of the forming process which in turn, can cause stress concentration in the blank and so the stability of local strain can be lost.

Successful design and further development of the process of hydromechanical tube forming requires taking into consideration every aspect of the applied technology and the interactions between different stages of the process. The following problems should be given a thought:

- quality and properties of a pre-formed tube,
- preliminary forming,
- bending and tube production methods,
- tool and matrix parameters,
- interaction between a matrix and a tube (wear, friction, lubrication),
- mechanism of strain, i.e. the character of welded tube flow (with or without the weld) at different zones of the tube,
- environment of the production process as well as the size and properties of hydroformed parts.

Research works on integrated, complex test stand for evaluating the properties of blanks and strips used in the process of forming and hydromechanical forming (hydroforming) have been carried out at the Department of Process Modelling and Medical Engineering at the Silesian University of Technology. First information on the design of the equipment for examining the tubes by hydraulic bulging tests using inner liquid pressure were presented in FORMING 2005 conference materials [4]. Complex test stand for examining drawability of blanks and welded tubes was prepared at the Department of Process Modelling and Medical

Engineering at the Silesian University of Technology [5]. Further improvements and modifications have been done so far in order to increase efficiency and accuracy of the tests. New technology for producing the samples of laser welded tubes has been prepared in co-operation with Company „Buczek Technologie S.A.“ in Sosnowiec and The Polish Welding Centre of Excellence in Gliwice.

2. Production technology of the samples of laser welded tubes

Technical potential of the equipment for bulging the tubes as well as the possibility of producing open-joint tube from welded tubes or blanks have been considered in the process of designing the test sample. Such welded tubes or blanks can be used for producing car body elements applying the method of hydroforming. Fifteen-stage system for bending and rolling open-joint tubes (Fig. 1) has been used in the production process at Company „Buczek Technologie S.A.“ in Sosnowiec.

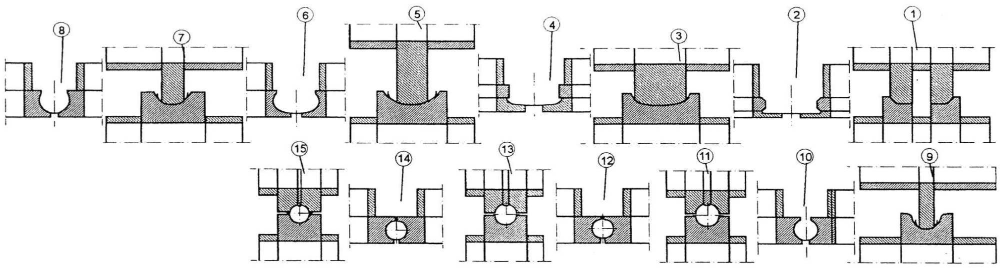


Fig.1 Diagram of roll calibration used for profiling and rolling the open-joint tubes

Basing on the results of the examinations of welding process of tailored blanks which was carried out at the Department of Process Modelling and Medical Engineering at the Silesian Technical University [6, 7] some more welding tests using Trumpf Lasercell 1005 equipment have been made. Advanced laboratory welding stand was equipped with an industrial robot and Nd:YAG laser produced by Trumpf HL 2006D (Fig. 2), owned by The Polish Welding Centre of Excellence in Gliwice.

Fig.2 General view of the welding stand for the process of welding by Nd:YAG laser produced by Trumpf HL 2006D [7]

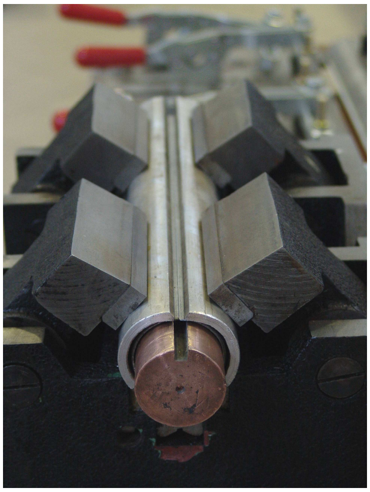


Fig.3 Photograph of a stabilizing device for tight fixing of a tube and the work of laser beam in the process of laser welding [8]

The carried out examinations at the welding stand proved that using robot with Nd:YAG laser of 2000 W power with f_c =200 mm working head which focuses the laser beam to form a spot of d_l = 600 μm diameter makes it possible to produce fault free, properly formed tailor welded elements of low hardness properties and favourable microstructure (the elements have been made of DX56D+Z steel grade of 1.5 mm thickness). Such tailor welded elements can be obtained in the process of welding both the tubes of 45 mm diameter made of that type of blanks as well as flat strips of 1000 x 145 mm. Accurate processing of the edge surfaces of tailored elements, their precise fixing in the stabilising equipment and correctly selected technical parameters of the process - all that is essential to get tailor welded elements of high quality [7].

Fig.4 Photograph of a sample of laser welded tube

Fig. 3 presents a photograph of a stabilising device for tight fixing of the tube so that the work of laser beam is precise in the process of laser welding, whereas Fig. 4 presents a photograph of a tube sample after the process of laser welding.

3. Further development of the test stand for examining tubes by inner liquid pressure in the process of bulging

The design of the equipment and the performed hydromechanical forming examinations should combine basic principles of the technology of liquid forming of welded tubes including the laser welded method. Some technological problems appeared at the stage of designing and in the course of the actual bulging tests of the tubes, therefore the following assumptions in designing the bulging equipment had to be made:

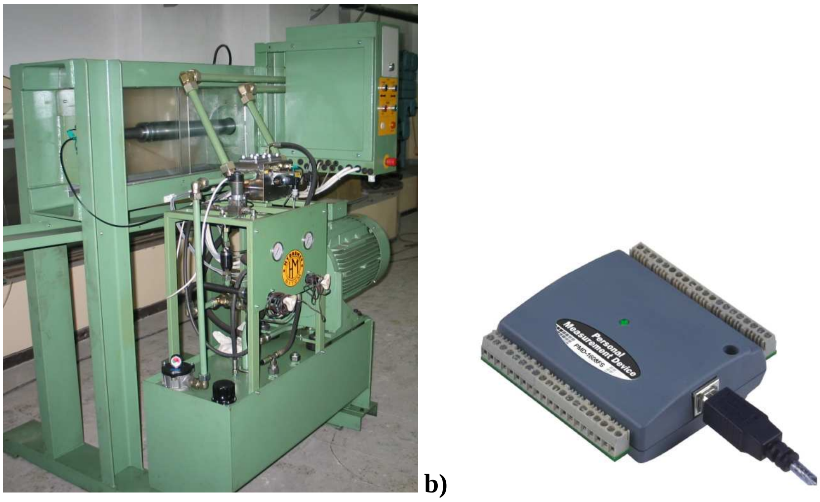
- maximal working pressure is $p_r = p_z$ = 1000 bar = 100 MPa because of the limited access to power supply systems and pressure measurement systems,
- for the assumed pressure, the outside diameter of the sample is d_z = 45 mm, wall thickness is g_0 =1.5 mm, tubes can be bulged till the value of their yield stress is reached, i.e. σ_P = 1500 MPa. These values have been derived directly from the following dependence:

$$p_r = \frac{2\sigma_p\, g_0}{d_z - 2g_0} \tag{1}$$

where: p_r - pressure which is used for bulging the tube [MPa],
g_0 - thickness of the tube wall [mm],
d_z - outside diameter of the tube [mm],
σ_p - yield stress of the tube sample [MPa].

For the majority of blanks used in the process of forming, yield stress does not exceed 600 MPa and that is why the equipment was provided with a two-range system of measuring and monitoring the pressure within limits of p = 400 bar = 40 MPa and p = 1000 bar = 100 MPa. Technical parameters of the equipment, control system for hydraulics and control and monitoring system were elaborated for the selected options.

Fig. 5a is a photograph of the equipment and a module of manual and automatic pressure control, whereas Fig. 5b shows data acquisition card which is the element of measuring-monitoring system for the stand of hydromechanical tube forming.



a) b)

Fig.5 Photograph: a) equipment for the process of free hydrobulging of tubes, b) data acquisition cards - one of the elements of measuring-monitoring system

Special device for taking the samples out from the movable and fixed head which tightens the ends of tube samples has been designed to make their dismantling easier. Measuring-monitoring system for evaluating the changes of bulging force and displacement of a tube sample, as compared to its initial position, has been tested as well. Non-hazardous work conditions for the equipment and the carried out tests have been defined.

4. Hydromechanical bulging tests

Basic characteristics of hydromechanical bulging process of tubes have been recognised regarding the process of free bulging of tubes by liquid pressure applied from inside. Principles and rules for tube hydroforming process have been elaborated which, in turn, enabled to produce tubes from laser welded blanks and further to introduce the process of hydromechanical forming. The presented results of experiments concern the process of hydromechanical, free forming of tubes of 270 mm long, of 45 mm inner diameter, made of blanks of g_0 = 1.5 mm thick - DX56D+Z steel grade. Initial examinations were carried out until strain stability was lost and tubes began to crack.

Co-ordinating nets of 5 mm mesh diameter were electrochemically mapped on DX56D+Z blank strips before producing open-joint tubes. It allowed to define the local strain distribution based on measurements carried out on the surface of laser welded tubes after the process if inner hydrobulging. Fig. 6 presents the bulged tube and the local strain distribution measured alongside the laser weld.

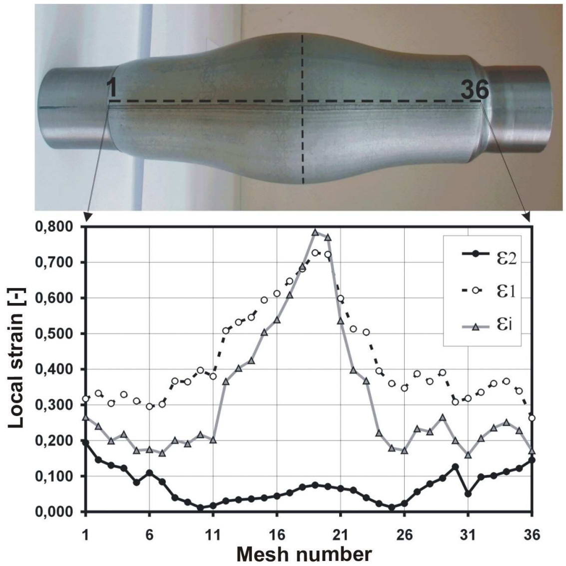


Fig.6 Local strain distribution measured alongside the laser weld on the hydromechanically formed tube

The results of hydromechanical bulging of the tube made of 1.5 mm thick blank of DX56D+Z steel grade have been compared to the results obtained in the hydrobulging process of laser welded blanks. The used blanks were of the same thickness and were made of the same steel grade in a round matrix of Ø 100 mm diameter. The results of hydrobulging of laser welded blanks in a round matrix of Ø 100 mm diameter have been presented in a more detailed way in paper [8].

5. Conclusions

The carried out bulging tests on tubes, using specially designed equipment for that purpose, allowed to examine uniform stress up to the moment when tubes begin to crack. It is also possible to control accurately the pressure which is essential for tightening and squeezing of the tube. The tests revealed that tightening is a very crucial element of the process and it can be applied several times only if the head edges of the sample tube have been properly prepared. The used diameters of the samples allow to map co-ordination nets in order to measure local strain.

The analysis of local strain distribution of hydromechanically bulged tube and the comparison of the obtained results to the results received in the process of bulging of laser welded blanks in a round matrix of Ø 100 mm diameter allow to draw the following conclusion: favourable mechanical state in the process of hydromechanical forming of tubes helps to reach higher values of ε_1 strain for the same values or the values corresponding to ε_2 strain values than those in hydrobulging tests performed in a round matrix of Ø 100 mm diameter.

Currently some more improvements of the equipment are being made so that the examinations of the process of tube bulging in closed matrices can be performed more thoroughly. The computer program for controlling the pressure and displacement is also being worked on because a good program allows to choose the desired p_r and p_z changes of pressure in the function of linear displacement of the heads against one another. The conducted examinations are the basis for physical verification of the results of numerical simulation of the analyzed process.

Acknowledgments

The financial support of the Ministry of Education and Science in years 2004-2007 as the research project no. 3 T08B 035 27.

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