DESIGN OF EXPERIMENTAL TOOL FOR TUBE HYDROFORMING

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When forming a material, its good formability is essential. It is primarily influence by mechanical properties and chemical composition of the material. Formability can be assessed by mechanical tests, or technological tests. Tensile test is one of the most common mechanical tests used to obtain basic mechanical properties of the material.

Another possibility how to evaluate the behavior of a material under given a load is to select a proper technological test with an appropriate experimental tool. Design of a tool should be simple, save and it should allow monitoring during the test, i.e. tube hydroforming. Article deals with design of experimental tool for the realization of experiments using radial hydroforming tubes whose ends will be fixed inside the tool because of an earlier setting of limit state of deformation.

KEYWORDS

formability, hydroforming of tubes, experimental tool

1 INTRODUCTION

To be able to get the idea about the behavior of tested material during forming, tensile test is usually performed. It is done under conditional of uniaxial state of stress. To get resultant theoretical calculations of yield strength of the material, the most commonly used equation is:

$$\sigma = K \cdot \varphi^n \quad (1)$$

Where K is material constant [MPa], n is strain hardening exponent [-] and φ is logarithmic deformation [-]. However, the computation based on equation (1) is inaccurate for most of forming processes, due to the fact, that values K and n obtain by uniaxial loading are used for the calculation. But in actual manufacturing of more complicated shapes of parts, complex stress-strain states occurs in certain places, it is usually biaxial state of stress and triaxial state of deformation. That's why application of n and K values obtained by tensile test brings an error into the theoretical calculations at the very beginning. Then it is more suitable to use a test, which would imitate the real loading of samples in practice as much as possible. It's called technological tests. In the area of tubes forming, the most often used technological test is buckling of the tubes by liquid - tubes hydroforming. It is important to note that the execution of the technological test is highly dependent on the design of experimental tool. The design of the experimental tool always depends on the results we want to achieve from the technological test. The requirements for the results are various, therefore there are currently many types of tools for tube hydroforming.

2 TESTING TOOLS

The construction of the tools is dependent on required results of experiments and their execution. The tools are designed either for forming of fixed ends or free ends tubes. We also need to consider the deformation behavior of material, because it has different results for free bulge forming (FBF) and for formed into the cavity. It is also important to decide if the axial force would affect the front of the tube or not during the buckling. Last but not least, workplace and financial resources play important role in design of tool. All the mentioned aspects need to be taken into consideration before we are able to create tools, which are simple and able to work even without complicated hydraulic systems and devices.

This kind of tool for testing of thin-walled tubes is described in the study [Lianfa 2006]. This tool uses its own internal hydraulic pressure source and its principle is based on fluid compression occurring inside the tool plunger. The inner part of the tool is filled with a liquid including the interior space of the tube. There is a chamber above the tube, which is separated from the tube by a seal, through which is going a hollow screw. This chamber is also filled with liquid and a plunger moves inside it in axial direction. While moving down, the plunger compresses liquid in the chamber and drives it into the tube through a hole in the screw, creating high pressure acting on the wall of the tube. As a consequence, there is a buckling, specifically in the location, where the tube is not fixed by the tool. The tool is used for 4 types of hydroforming, meaning bulge forming of fixed ends or free ends tubes, either with or without axial loading. It is possible to use the tool for testing of various tube diameters thanks to easy exchange of lower and upper supporting dies.

Another (but very similar) tool was designed and constructed by [Lianfa 2008], with different principle of liquid pressure. The liquid is present only inside the tool. The tube ends are fixed in the tool by lower and upper supporting dies, whose distance is limited by back-up ring. This back-up ring determines the space for tube's buckling. Both dies along with the tube and back-up ring form a unit, which moves in a containment vessel in axial direction and the whole system works on the principle of hydraulic cylinder with plunger. There is a liquid at the bottom of the containment vessel, which flows through a hollow screw into the tube, when the dies with the tube are moving downwards. This screw goes through the lower die and a seal and it ends up in the lower part of the tube. When more liquid is added into the tube, the pressure inside the tube is increased and consequently the buckling occurs.

At the university in Brescia [Bortot 2008], they have to at their disposal, which they designed and produced and which uses a hydroforming device. It is possible to test a greater scale of diameters and thicknesses of tubes in this tool thanks to easy exchange of several components.

A tool composed of a pair of identical supporting dies halves is designed and constructed in [Boudeau 2012]. The tested sample is bulged between those dies. The fluid is brought into the interior space of the tube through a drilled hole in upper capsule. The buckling occurs in a properly designed cavity in the middle of the dies. The height of the buckling is scanned inside the tool by a position sensor.

There are many other testing tools, with more or less complex construction. And as mentioned earlier, there construction always depends on the conditions of the experiment and on the required results. However, most of the construction solutions do not provide the possibility to monitor the whole process of buckling and therefore it doesn't allow creating video recordings or pictures. That's why as part of our research we wanted to design a tool which would allow to monitor the whole process of buckling and enable to use highly accurate and modern way of deformation measurement by non-contact 3D optical measuring system ARAMIS. Apart from that, there were other requirements for the tool, which will be described in the next chapter.

3 DESIGN OFEXPERIMENTAL TOOL

As suggested above, the construction of the designed experimental tool should be simple, sufficiently solid (due to anticipated high pressure acting inside the tool, more precisely inside the tube), easy to dismantle and the area of tube strain must be visible. To be able to use it in common workshops and to be able to use any press machine or any tensile testing machine for generation of press force, the tool must have a simple and transportable way of filling and draining by means of manual pump. That's why the tool is designed with its own inner hydraulic pressure source, which doesn't require a complicated hydraulic system and a specific workplace. Another requirement for the tool was to have simple fastening of the tube in the tool in order to prevent axial shifts of tube ends during hydroforming. This means hydroforming of tubes with fixed ends. And finally the buckling process itself should be in the way of free bulge forming, to be able to achieve even limit values of hydroforming, when a crack appears. The tool is defined for a steel tube testing sample with parameters D = 28 mm, t_0 = 1 and 1.5 mm, length L = 83 mm. All these aspects had to be taken into consideration for the design of the experimental tool for buckling.

Number of key problems had to be solved during the project. The problems and their details are discussed in the next part of this article, including description of the tool's function. You can see 3D model of the designed tool on Fig. 1.

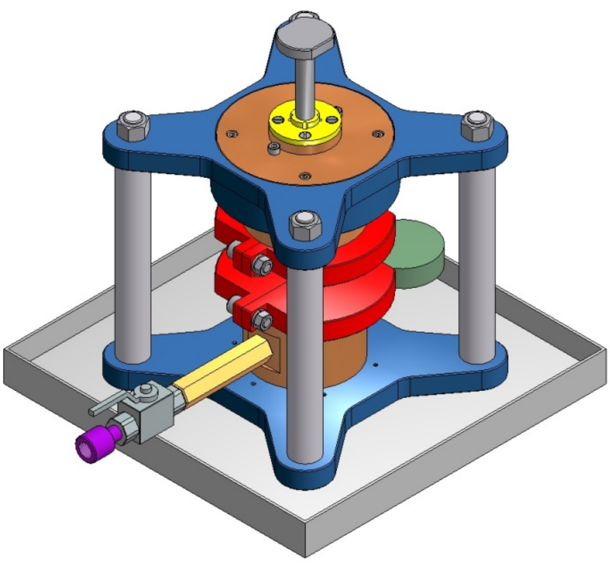

Figure 1. The complete three-dimensional model of the proposed tool

Lower part of the tool consists of a lower plate with four fixed pressed pillars. Lower sleeve is inserted in the lower plate and connected by screws to it. Lower supporting segmented die is inserted and centered in the lower sleeve, where a tube with welded flanges is placed.

On the pillars, upper plate is placed with inserted upper sleeve, including a guide sleeve and a plunger and it is secured by nuts. The upper part of the tube is fixed inside the upper segmented supporting die. The plunger in the upper sleeve is used as a fluid container. The fluid is required for compensation of volume of increased interior space of the tube during buckling. The guide sleeve is inserted in the upper sleeve for setting of the plunger in specific position. There are four walk-through holes for draining of fluid, which would get above the plunger through breather holes while the plunger is going downwards. With regard to the usage of liquid during buckling process, grooves for seal O-rings are designed in lower and upper sleeve for static purposes. The grooves are also designed in the plunger, with seal O-rings again, for dynamic purposes this time.

A digital pressure gauge with type designation LEO 1 produced by Keller company is attached to lower sleeve and it enables to measure pressure up to 100 MPa. Here is also hexagonal connection, which delivers liquid from the pump to the tool. To the connection (with seal O-rings again) is attached a closing valve and a screw coupling for connection with the pump. Then the liquid is moved by the pump into the tool. When the liquid starts to leak from the upper breather holes and it is obvious that there is no more air in the tool, the pump would be stopped and the upper holes would be screwed. After that pressure valve would be closed, in order to prevent damage to the manual pump. Testing machine ZD40 generates pressure force on the plunger and moves it downwards. With gradual shift of the plunger, the pressure in the liquid increases and consequent free bulge forming of the tube occurs. A cover made of polycarbonate is placed in front of the testing machine ZD40 for the safe conduct of tube's testing and especially the protection of persons operating the machine at that moment, when the deformation of tubes would reach a critical degree, which means when the cracks start to appear. After the tube cracks, or after the test is completed, the plunger is pulled back to its initial position and the liquid located above the plunger flows through holes in the guide sleeve out of the tool. The supporting dies are removed, the nuts are unlocked, the upper plate is removed together with the upper sleeve, the guide sleeve and plunger, and subsequently it is possible to remove the tube from the tool. The forming liquid located inside the deformed tube is captured into the prepared basin which is placed under the tool. The liquid can then be used again prepared for another testing process.

The key elements for the construction and design of the test tool are discussed in more details in the next chapters.

3.1 Fixing the tube ends

One of the important points for construction of the tool is how the tube is fixed within the tool. The tool is designed to have the tube ends fixed, in order to prevent any move of the tube in axial direction. Therefore, both tube ends were modified and circular flanges of sheet metal were welded to them by laser.

Fixing and centering of the tube ends in the tool is performed using the two divided supporting dies. Fixing of the tube in the lower sleeve can be seen in cross section view in Fig. 2. The supporting dies are designed to encircle the tube around its entire circumference. The sleeve is joined with the supporting die by two screws.

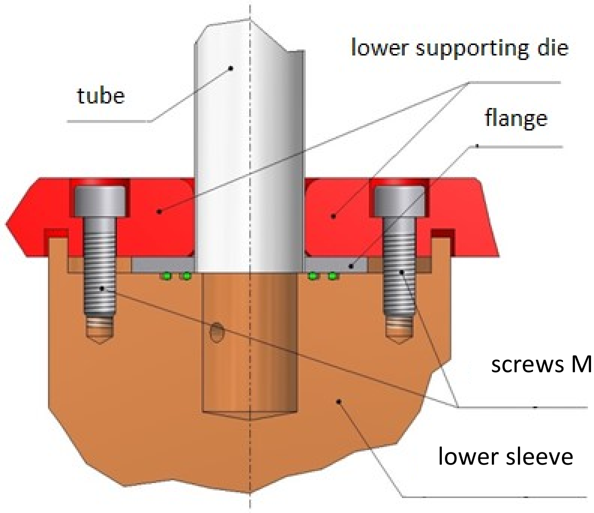

Figure 2. Fixing of tube ends – cross section

3.2 Seal

For the experiment with buckling realized by fluid pressure, it is necessary to design a sufficiently dependable seal to prevent leakage of the forming liquid, which would negatively impact the results of the experiment.

The seal between welded flanges and the lower (or upper) sleeve, also the seal in the space between the upper sleeve and the moving plunger and the seal between the connector connecting the closing valve and the lower sleeve. Seal O-rings were used for all the three types.

Seal between the welded flange and the sleeve

It can be seen in Fig. 2 how the seal between the lower (or upper) sleeve and the welded flange on the tube end is implemented. O-rings are fitted into the standard-designed grooves in the upper and lower sleeve. Subsequently, they are the axially compressed during the clamping of tube in the tool. This leads to the axial deformation of the O-ring, sealing between the flange and the sleeve and it prevents the fluid leak from the interior of tool, or more precisely the tube.

Seal between the plunger and the upper sleeve

Scheme showing plunger seal is shown in Fig. 3. Two O-rings are used, for the security reasons. Because the plunger is moving during the buckling process, it is necessary to use seals for moving joints. When designing a seal between the plunger and the upper sleeve, the distance between O-rings was also a key point. If they are close together, the pressure might decrease while the plunger passes the breather holes and that would influence the final results of the experiments. Therefore the O-rings were designed in a way that at least one of them is always in contact with the surface of the hole in the upper sleeve. This ensures reliable seal of the plunger throughout its movement downwards without losing pressure.

Seal between the connection linking the closing valve and the lower sleeve

The last solved seal is sealing the space between the connection and closing valve as it can be seen in Fig. 4.In this case, the compression is done in axial direction, when mounting the closing valve and the connection.

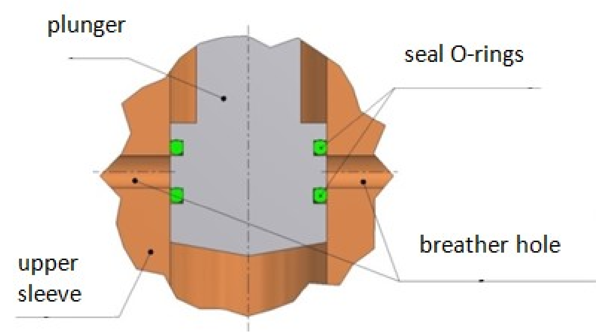

Figure 3. Plunger seal – cross section

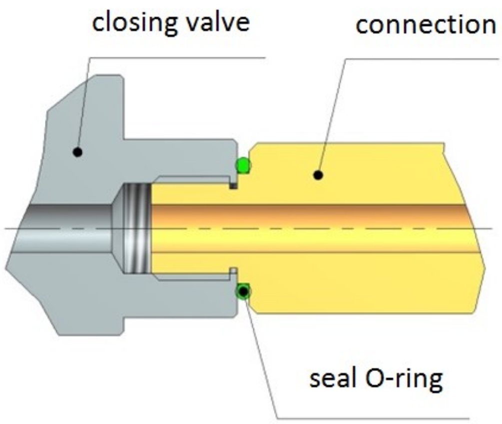

Figure 4. Seal between the connection and closing valve – cross section

3.3 Tool loading

Filling of the inner space of the tool, or more precisely the tube, is realized by a manual pressure pump. The pump is attached to the tool by a screw coupling, closing valve and the connection, as can be seen in Fig. 5.Hydraulic high-pressure valve with a pressure resistance of 50 MPa was used, which should be sufficient according to preliminary calculations. An oil with designation HM-46 was chosen as the forming liquid which will be pumped into the tool. It is high-quality hydraulic oil designed primarily for hydrostatic hydraulic mechanisms, particularly for high-pressure types.

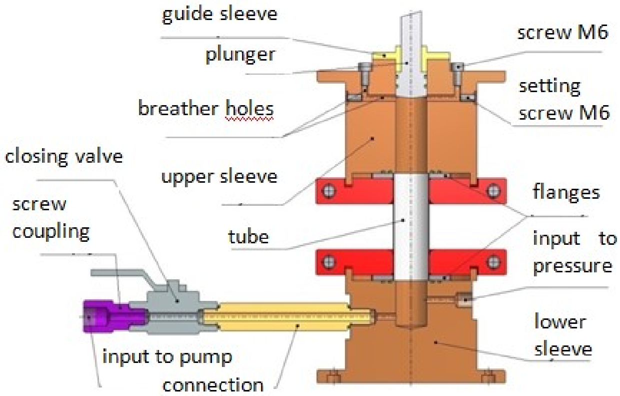

Figure 5. Filling and venting system

3.4 Venting system

Filling of the interior of the tool is performed by the pump, as mentioned above, in the direction from the lower sleeve to the upper sleeve. Venting system is used to remove air from the interior of tool, to prevent possible influencing of test results.

Venting during the filling is realized by pressing the liquid by the pump pressure from the lower sleeve toward the upper sleeve and the breather holes.

When it is clearly visible, that all the air is forced out (liquid without air bubbles starts to flow through the breather holes), the holes will be closed by a pair of screws. In order to ensure sealing around the bolts during the forming process, Teflon tape is applied around the thread. Since the plunger moves just a little bit at the beginning of the process, there is not such a high pressure that would break the seal. When the plunger gets under horizontal holes, sealing of the bolts is no longer stressed.

4 CONCLUSION

In the study, the design and construction of experimental tool for hydroforming of thin-thickness tubes with fixed ends is described. The main advantage of this tool is the possibility to monitor the experiment during the testing and subsequently it enables the usage of highly accurate and modern way of deformation measurement by non-contact 3D optical measuring system ARAMIS. Further advantages of the designed tool are its simple construction, effortless demountable, safeness and utilization in common workshops, especially thanks to simple way of filling without complicated hydraulic systems and devices. The tool was made according to the design and we are currently testing it at our workplace.

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