AIP | Conference Proceedings

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Citation: AIP Conf. Proc. **1315**, 1285 (2011); doi: 10.1063/1.3552361
View online: http://dx.doi.org/10.1063/1.3552361
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1315&Issue=1
Published by the American Institute of Physics.

Miniaturization of the tube bulging test

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Abstract. The paper focuses on the miniaturization of the bulging test for material characterization of micro tubes. For the design of the experimental device, numerical simulations are conducted first. Even if no scale effect is taken into account in material modeling, numerical results give some information before designing the set-up and performing experimental works: level of pressure inside the tube, volume of fluid necessary to create such a level of pressure and bulge height to measure. The main results are a design of the experimental device and choices for its instrumentation.

Keywords: Micro tubes, Bulging test, Set-up design, Instrumentation
PACS: 81.20.Hy – 83.50.Uv

INTRODUCTION

Tube hydroforming is an advanced process that presents several advantages [1] such as 1) part consolidation with the improvement of the structural strength and stiffness 2) lower tooling cost due to the diminution of the number of passes and of secondary operations 3) weight reduction through more efficient section design 4) wall thickness tailoring and narrow dimensional tolerances with low springback.

Nowadays components miniaturization concerns a lot of sectors of activity: aerospace, automotive, biomedical, etc. It is therefore legitimate to study the miniaturization of traditional forming processes [2][3]. They could present the advantages of less environmental impact than micro manufacturing processes derived from microelectronics. Moreover these microforming processes can inherit all the methodology and knowledge from traditional forming processes in simulations, material modeling, etc. The main difficulty identified at the present time is the material characterization in small dimensions and it is proposed to develop a specific device for micro tube bulging test.

Numerical simulations will be conducted in order to evaluate the interesting dimensions to be changed for a future study of the scale factor influence. The results will give some orientations for the design of the experimental device and its instrumentation.

CP1315, *International Conference on Advances in Materials and Processing Technologies (AMPT2010)*
Edited by F. Chinesta, Y. Chastel, and M. El Mansori

NUMERICAL SIMULATIONS

General considerations

To perform finite element simulations of the micro tube bulging test, assumptions based on experimental works done on macro tubes [4] are done: 1) the tube is clamped at its two ends 2) the tube can bulge only in its central part named the free bulge zone.

So the test presents a cylindrical and mirror symmetry. Only the mirror symmetry is considered in the following (Figure 1).

Basic finite element simulations are conducted in order to 1) design the experimental device 2) choose sensors for adequate measurement 3) identify the interesting parameters for scale effect study.

The material is modeled by the following hardening law: $\sigma_0\left(\bar{\varepsilon}^p\right)=\sigma_Y+K.\left(\bar{\varepsilon}^p\right)^n$.

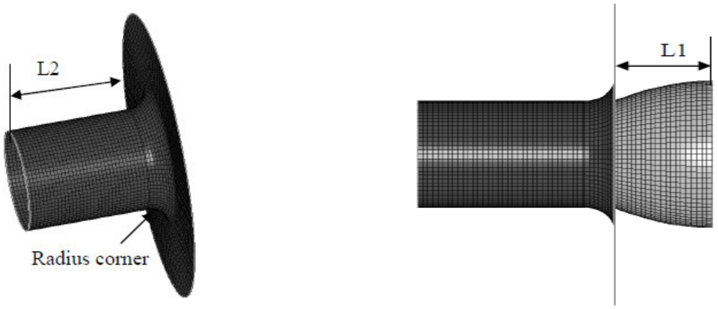
The simulations are performed with LS-Dyna® program using an explicit dynamics algorithm. Material data of Table 1 and test parameters of Table 2 are adopted for the simulations.

TABLE 1. Material data for the micro tube

Data	**Values**
Density	7 800 kg/m^3
Young's modulus	210 000 MPa
Poisson's coefficient	0.3
Yield stress	285 MPa
Consistency	1 250 MPa
Hardening exponent	0.4

TABLE 2. Parameters of the micro tube bulging test studied in this paper

Dimensions	**Minimal-Maximal values**	**Reference values**
Die length (L2)		6 mm
Die radius corner	0.1 – 0.9 mm	0.1 mm
Half bulge free length (L1)	3 – 10 mm	3 mm
Tube diameter (D)	3 – 4.5 mm	4 mm
Tube thickness (t)	0.05 – 0.3 mm	0.3 mm
Ratio Diameter/Thickness	10 – 80	~13.34



Half die

Half die (left) – Half tube (right)

FIGURE 1. Finite element model for micro tube bulging test.

Loading conditions

As already mentioned, in tube bulging test, the tube is loaded with an internal pressure. During experiments, the pressure results in filling the tube with an increasing volume of fluid. In LS-Dyna® code, two ways are proposed for modeling the increasing internal pressure: 1) an internal pressure is applied on each finite element representing the free region of the tube 2) internal pressure is calculated by the way of a volume control algorithm.

Figure 2 shows the evolution of the bulge height and the pressure for these two loading conditions. Volume control leads to a smoother evolution of the bulge height that guaranties a more homogeneous zone essential for material characterization (Figure 2.a). Important results for future design are evaluated such a typical pressure to be generated in the tube (~100MPa), typical bulge height to be measured (1.2mm) and typical feeding volume for the test (~44mm^3).

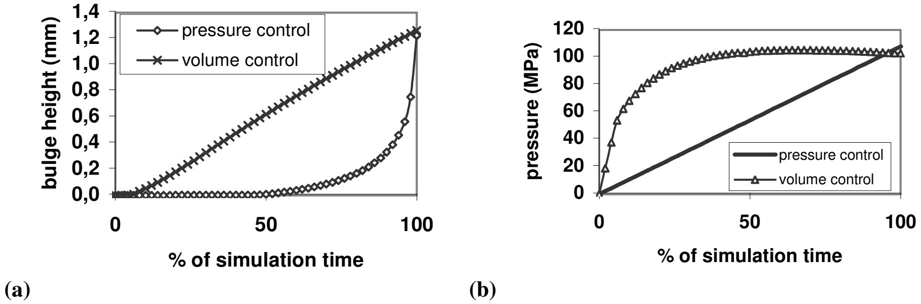


FIGURE 2. Simulations done with pressure or volume control for a tube with dimensions (L1 = 3 mm ; D = 4 mm ; t = 0.3 mm) (a) Bulge height vs. % of simulation (b) Pressure inside the tube vs. % of simulation.

Die geometry

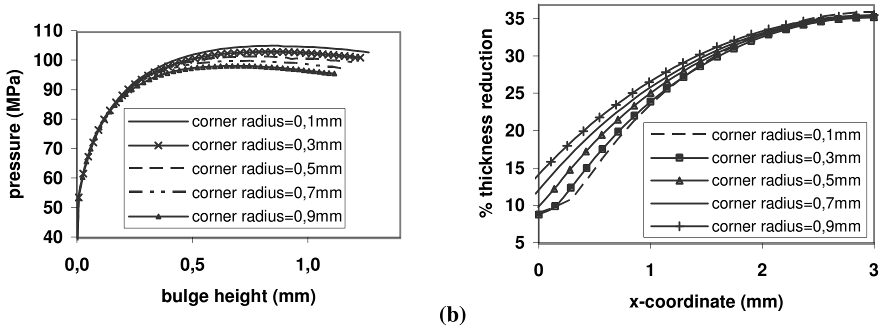
Die geometry can affect boundary conditions especially the die corner radius. So simulations with different values for the corner radius have been carried out and analyses have been focused on the stress level in the tube in this particular region and on the thickness reduction along the free bulged zone of the tube.

It can be observed in Figure 3.a that stresses can become very high in this area when the die corner radius is small that implies an increasing risk of premature crack during the bulging test. In Figure 3.b, it can be seen that the thickness reduction at the pole is not affected by the corner radius, but its evolution is smoother for the larger values of the corner radius.

Scale effects

Here basic finite element simulations explore the effect of changes in dimension on the global response. For an efficient usage of the future experimental measurements, it is necessary to order the different tests to be performed and it is chosen to impose the ratio diameter/thickness. It permits to pilot the number of grains in the thickness and to study scale effects.

In Figure 4, the influence of the ratio diameter/thickness on the pressure vs. bulge height curve is illustrated. For small ratio, the pressure presents a maximum and decreases. For higher ratio, the maximal and stabilized pressures present the same level.



(a) **(b)**

FIGURE 3. Effect of the die corner radius on (a) the stress level near the die corner radius (b) the thickness reduction along the deformed tube.

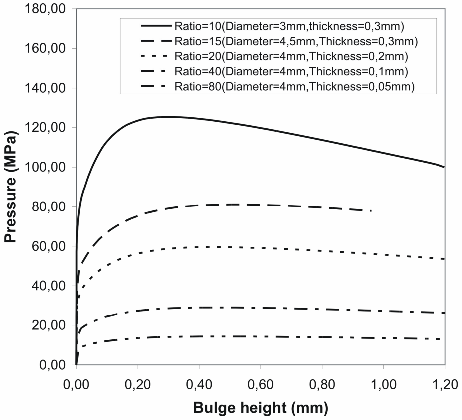


FIGURE 4. Influence of the ratio diameter/thickness on the pressure vs. bulge height curve (L1=6mm)

DESIGN AND INSTRUMENTATION

Design constraints

The bulge tube device to be designed will be implemented on a tension/compression machine available at the laboratory. It will be built in two parts: 1) a plunger to generate the pressure inside the tube 2) the die that will guide and maintain the tube during the deformation. Instrumentation must be implemented for measuring the pressure and the bulge height.

Instrumentation

For material characterization and with analogy with traditional tube bulging test [4], measurements to be done are essentially the bulging height and the pressure inside the tube.

The pressure will be measured through the force cell of a tension machine. Some leak can occur during the test. It could be interesting to place a displacement sensor for measuring the plunger displacement. It will permit to evaluate the pressure of the fluid injected in the tube and the leak of fluid.

For bulge height measurement, contact must be avoided for such tube dimensions. Moreover a single point measurement can lead to errors on the stress-strain curve [5] especially with so small tubes. So a laser line scan sensor is chosen that will permit to get 640 measure points on a length of 20mm over the profile of the bulged micro tube with a precision of 2µm. This sensor needs a window in the die large enough for the passage of incident and reflected rays.

Design

The device is designed in two parts: the die and the plunger.

The die (Figure 5.a) possesses several functions: 1) it guides and maintains the tube 2) it assures the tightness 3) it permits the free bulging 4) it allows the bulge height measurement.

Guides are obtained by conical machining in the two half dies. Conical machining associated with conical plungers assures the tightness and clamp the tube at its two ends. In the inferior plunger a vent hole permits air evacuation during tube filling with fluid. In the upper plunger a channel allows fluid feeding to create internal pressure. A cavity is machined for tube free bulging. Finally a window is created for bulge height measurement with the laser sensor.

The plunger (Figure 5.b) is built in two parts: the primary and the secondary plungers. The primary plunger presents a small diameter and generates the pressure inside the tube. Its small dimensions will permit precise evaluation of volume feeding by following its displacement with an adapted sensor. The secondary plunger is linked to the force cell of the tension machine. It has a higher diameter and can play the role of guidance for the primary plunger.

The complete set-up and its implementation on the traction machine is illustrated in Figure 5.c.

CONCLUSIONS

Miniaturization of processes is a necessity for a lot of applications. One of the difficulties is material behavior that becomes sensitive to microstructure. For tube hydroforming miniaturization it is essential to develop first an experimental set-up for micro tube bulging test. Basic finite element simulations have been carried out to get some evaluations about pressure to develop, effort to resist to, volume to control, displacement to measure. These evaluations were essential to design the experimental device and propose adapted instrumentation.

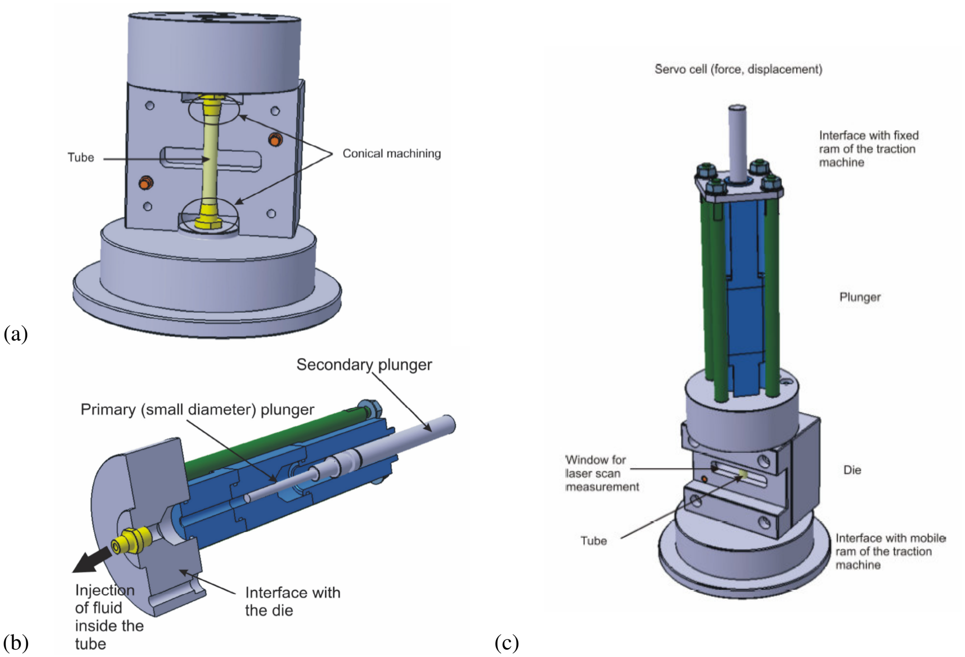


FIGURE 5. Design of (a) the die (b) the plunger and (c) the complete set-up with its implementation on the traction machine.

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