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NUMERIC SIMULATION OF THE HYDROFORMING PROCESS FOR A TUBULAR PART IN A BICYCLE FRAME

Tudor E. MORAR, Gheorghe ACHIMAŞ, Nicolae MIHĂILESC, Sorin ACHIMAŞ, Florin MOCEAN

Abstract: Hydroforming is a manufacturing process with increasing appeal to manufacturers in high technology domains, as well as to manufacturers of household goods. This technology uses pressure exerted by a hydraulic medium to shape a tubular part. Tube hydroforming is being frequently used to produce bicycle parts, given the advantage of eliminating welding operations which require expensive installations. Furthermore, the ratio between the mechanical strength characteristics and the weight of hydroformed parts is extremely favourable, contributing to significant reduction of product weight.
Key words: *hydroforming, bicycle, tube hydroforming, mould hydroforming.*

1. INTRODUCTION

Hydroforming process is based on inflating a tubular part, accompanied by radial or axial compression. Hydroforming may be divided into two broad classes [1]:
- Free hydroforming (fig. 1,a) ;
- Mould hydroforming(fig.1,b şi c).

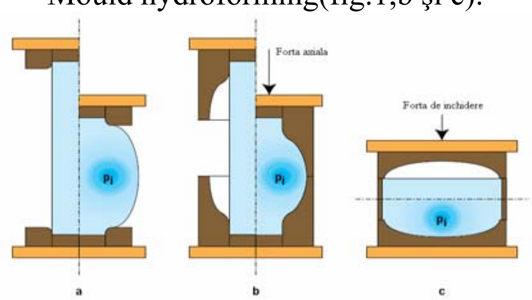


Fig.1 Types of hydroforming process: a – free hydroforming; b – mould hydroforming with longitudinal separation plane; c – mould hydroforming with cross-sectional separation plane

Mould hydroforming is divided according to the mould used, such as:
-Mould hydroforming with longitudinal separation plane (fig.1,b) ;
-Mould hydroforming with cross-sectional separation plane (fig.1,c) .

After hydroforming the part exhibits a large level of dimensional stability and strength. Due to the three axial tensions in tube's walls the material is highly deformable.
In the case of mould hydroforming, lubricants are required to control the effect of friction on the part and mould. Certain parts can be brought to the intended shape only by using adequate lubricants. Lubricants allow for the reduction of thickness variations in the part's walls. Defects most frequently affecting the quality of hydroformed parts are [2]:
-wall breaking (fig.2);
-occurrence of creases;
-buckling.

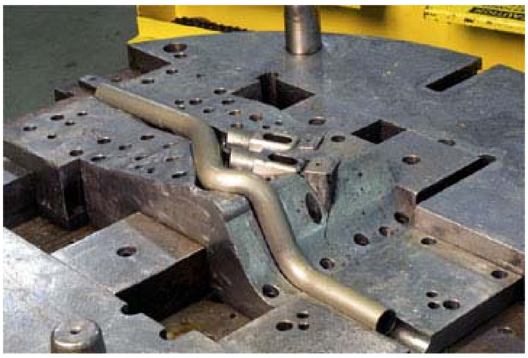
Fig. 2 Parts with walls reaching breaking point during hydroforming process

Usually, breaking is caused by exceeding the material's deformation capability by incorrectly designing the part's geometry, improperly distributing deformation stress on consecutive operations or not using proper lubricants.

2. HYDROFORMING APPLICATION FIELDS

Technological capabilities of hydroforming allow for creating complex geometry products with a reduced number of components, good mechanical strength and low weight. The process may be applied to various configurations of semi-finished products (fig. 3). Given this particular aspect, hydroforming is being used in several fields, such as:
-car manufacturing;
-aviation industry;
-consumer goods industry;
-joints and complex tubular parts.

a)



b)

Fig.3 Products made with hydroforming: a – bicycle frame; b – complex geometry tube

Major advantages of tubes hydroforming are the following:
-possibility of forming parts with complex configurations in a single operation;
-optimal use of material's plastic deformation capacity;
-constructional simplicity of moulds.

As a disadvantage, hydroforming requires the purchase of specialised equipment and working at high pressure.

Hydroforming good quality tubular parts requires proper design of process parameters. Also, properly sizing the initial semi-finished product is very important.

3. NUMERIC SIMULATION OF THE HYDROFORMING PROCESS FOR A TUBULAR PART IN A BICYCLE FRAME (fig.3,a)

3.1 Presentation of finite element analysis software DYNAFORM

DYNAFORM is one of the most used applications in the field of finite element simulation of hydroforming. Among the features of this application, the following should be mentioned:
-possibility to import geometric models of parts and/or tools designed in the most usual CAD programs (CATIA, SolidWorks, SolidEdge, AutoCAD etc.)
-automated discretisation into finite elements of the parts and tools;
-assistance in preparing process models (defining deformation steps, positioning tools against the part, defining variation diagrams for process parameters, such as the pressure acting inside the tubes);
-using high performance plasticity models, which take into account the anisotropic properties of laminated or pulled tubes (e.g. Hill 1948, Barlat 1989, Barlat 2000 etc. models);
-availability of library containing mechanical properties of most frequent industrial materials;
-modelling the contact with friction between the part and the tools;
-availability of a post-processor providing detailed graphic presentations of simulation results (distribution of part's thickness, analysis of breaking risk, folding risk, as well as the material stretching status etc.).

The advantages listed above, together with the fact that the Laboratory of cold pressing technology within the TCM department owns a DYNAFORM license, determined the selection of this application for simulating hydroforming of aluminium and copper tubes.

3.2 Numeric simulation of hydroforming process

An elastoplastic material model has been adopted to describe the mechanical behaviour of the tube. This model describes the elastic part of the deformation through a Hooke type linear law, which includes two material constants: Young's modulus (E) and Poisson's ratio (ν). To describe the irreversible part of the deformation, the material model uses a Barlat 1989 plasticity criterion and a Hollomon hardening law:

Mechanical characteristics of aluminium AA6060-T4 Table 3.1

Elastic constants	E	$6{,}82 \cdot 10^4$ N/mm^2
	v	0,33
Hollomon hardening law constant	K	334,1 N/mm^2
	n	0,23

Mechanical characteristics of copper (Cu 99,9) Table 3.2

Elastic constants	E	$8{,}5 \cdot 10^4$ N/mm^2
	v	0,32
Hollomon hardening law constant	K	365 N/mm^2
	n	0,185

Tables 3.1 and 3.2 present the values of material constants defining the elastoplastic model for aluminium AA6060-T4, and copper respectively (Cu 99,9).

3.3 Preparing the geometrical models of the tubular part

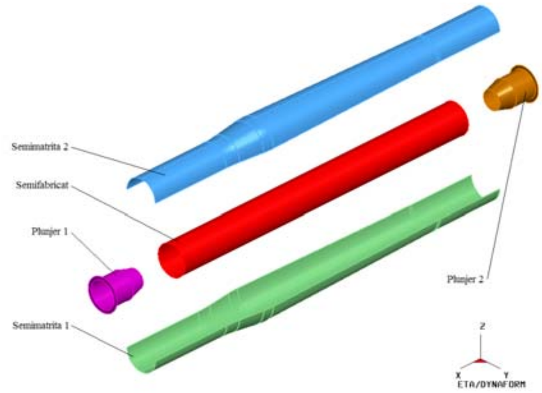


Fig. 4 Importing geometric models of the part, of semi-moulds' active surfaces and plungers into DYNAFORM

The tubular part, as well as the active surfaces of the semi-moulds and plungers have been modelled using the assisted design application SolidWorks 2008. Geometric representations have been exported to DYNAFORM as IGES files (fig. 4).

3.4 Discretisation of geometric models of the part and tools

Median surface of the part has been discretized into finite elements as a flexible shell (fig. 5). Since the tools and the plungers are subject to negligible deformations as compared to the part, rigid face elements have been used for their discretisation (fig. 6).

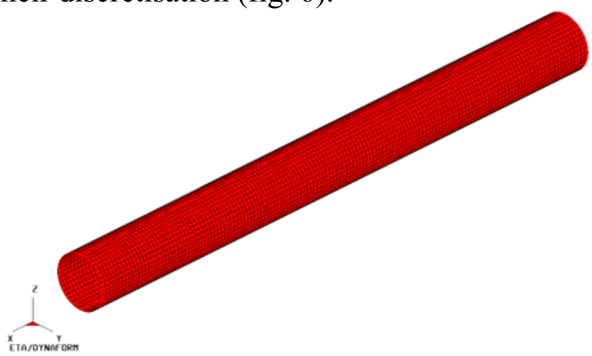


Fig. 5 Discretisation of the median surface of the tubular part into finite elements as a flexible shell

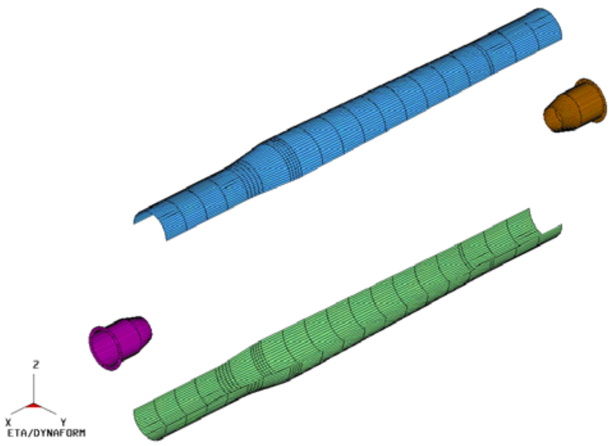


Fig.6 Discretisation of semi-moulds' and plungers' active surfaces into finite elements as a rigid face

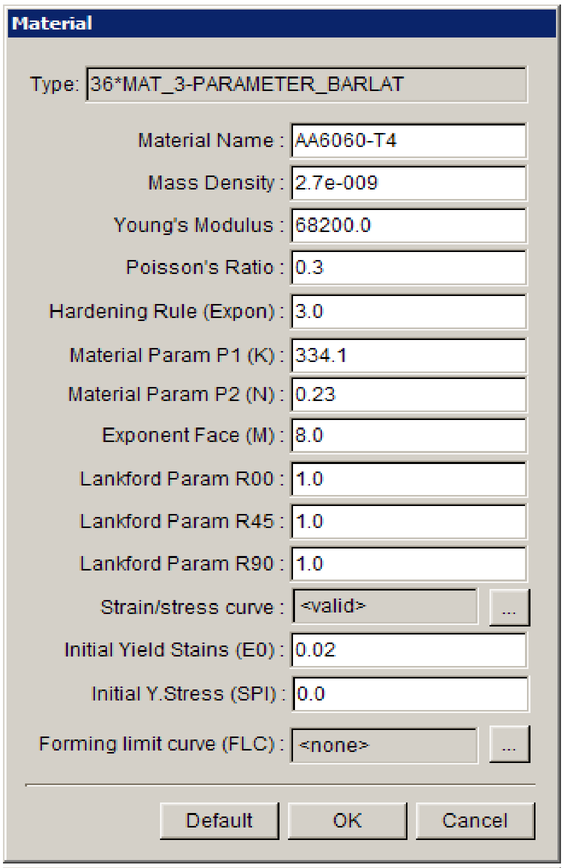
3.5 Description of process subject to numeric simulation

DYNAFORM application provides the user with the AutoSetup function, where all parameters of the hydroforming process can be set. Graphic interface of the AutoSetup function is structured into several dialog boxes. The information input in the fields of the respective dialog boxes is presented below.

General characteristics of the process to be analysed:
-class of the process – deformation of a tubular part;
-nominal wall thickness: 1,5 mm for aluminium, 1 mm for copper;
-type of process: hydroforming.

Give a title to identify the results of numeric simulation;

Define mechanical properties of the tubular part:
-Select mechanical model as shell
-Specify parameters defining the elastoplastic model associated to the part (fig. 7, 8, 9 and 10).



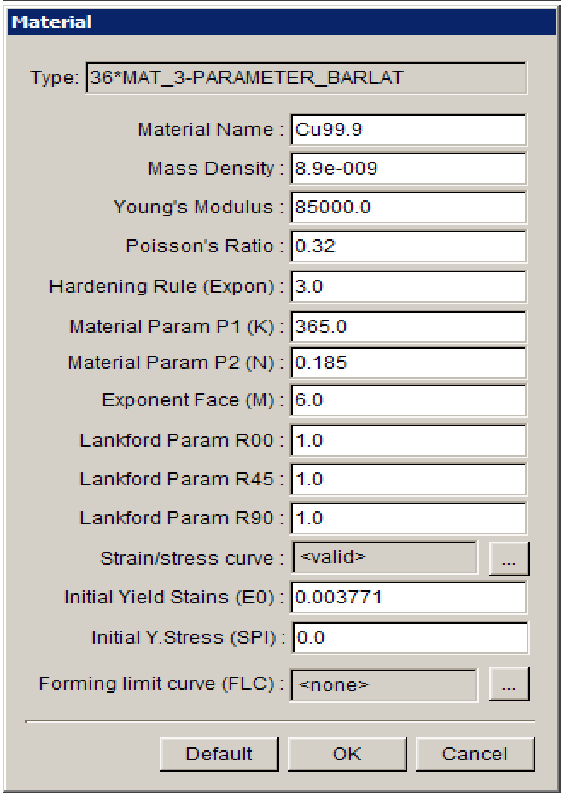


Fig. 7 - Fig. 8 Values for parameters defining the elastoplastic model associated to the part, for aluminium and for copper.

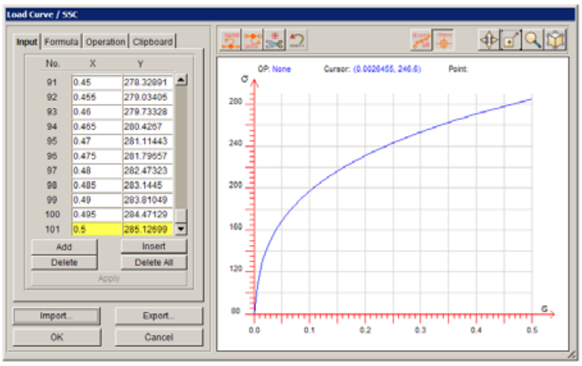


Fig. 9 Hardening graph for an aluminium part

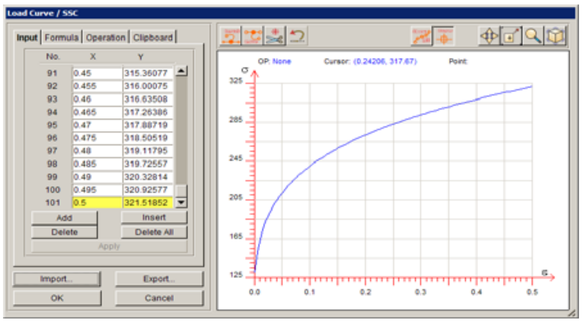


Fig. 10 Hardening graph for a copper part

Specify tools cinematic and parameters defining the friction interaction between the part and their surfaces:
-define direction of movement for each tool included in the process model;
-automated positioning of tools in relation with the part (fig. 11).

Fig. 11 Automated positioning of tools in relation with the part

Specify parameters defining the stages of hydroforming process:
-status of each tool included in the model, active or inactive, type of tool control applied force, pressure or imposed displacement, as well as total duration of simulated process
-tabular descriptions of variation of parameters defining the hydroforming process control – law of pressure variation inside the tube (fig. 12)

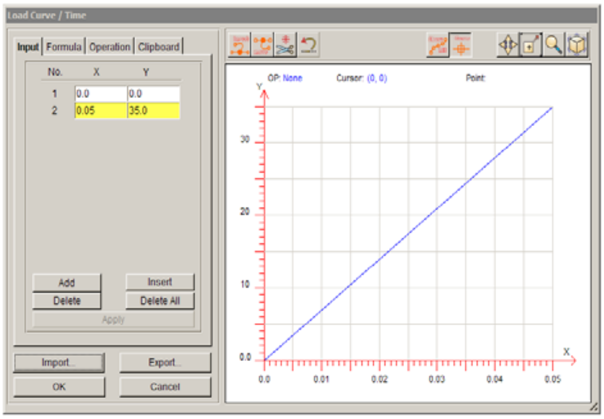


Fig.12 Law of pressure variation inside the tube, both for aluminium and copper

Of all the information provided by the postprocessor, a module of DYNAFORM application which graphically presents the distribution of status parameters of the part in various stages of deformation (thickness, deformation, tension etc.), the most significant from the technological point of view are the following:

- evaluation of risk for deformation in the final stage of the process (fig.13-fig.14).

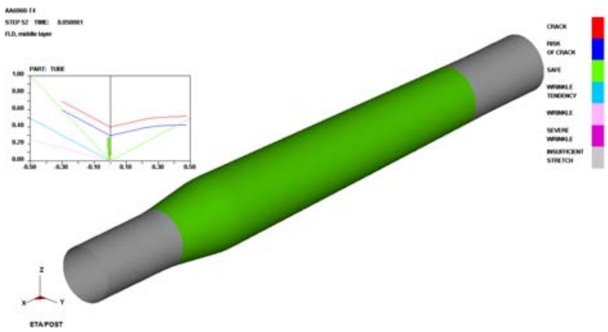


Fig.13 Analysis of risk for final deformations of the aluminium part

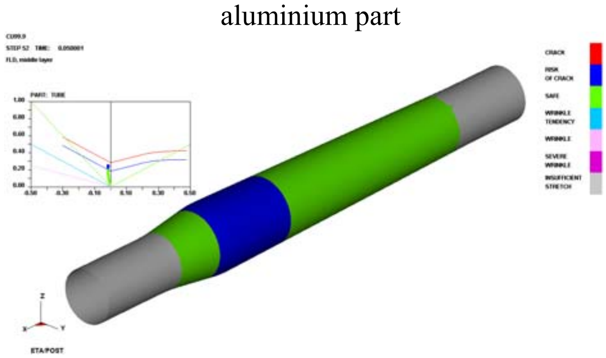


Fig.14 Analysis of risk for final deformations of the copper part

For evaluating the risk of strangulation or breaking occurring in the part, the postprocessor uses a limit deformation curve. This is a diagram using pairs of main deformations to define the total amount of strangulation or breaking occurrences in the material.

The box in the top left of the diagram in figures 13 and 14 contains two limit deformation curves. The red curve corresponds to material breaking conditions. The blue curve is equidistant traced 0.1 lower. It represents the conditions where the risk of strangulation is already present.

Obviously, most of the times, the occurrence of strangulation causes the rejection of parts. In the specific case of hydroformed tubes, the areas with severely reduced thickness due to strangulation have a lower mechanical strength and present a potential risk in the operation stage. Therefore, the simulation results may be considered as acceptable only if all surface deformations are in the area below the inferior limit curve. As seen in the diagram in figures 13 and 14, the entire area of the hydroformed part is green. This colour code corresponds to the safe zone of deformations located below the strangulation limit curve. Also to be noticed that the gap between the largest deformations and the inferior limit curve is quite small. This situation presents an optimal usage of material's deformability.

The diagram in figure 15 presents significant variations of tube wall thickness. As expected, the hydroformed area is thinned. The most reduced thickness for the aluminium part is of approximately 1.25 mm.

The diagram in figure 16 presents significant variations of tube wall thickness. As expected, the hydroformed area is thinned. The most reduced thickness for the copper part is of approximately 0.87 mm.

4. CONCLUSIONS

This paper presents the preparation of a finite element model for the hydroforming experiments using DYNAFORM software. Selection of this particular application is justified by its capacity to simulate plastic deformation processes on tubes, as well as the availability of an academic license at the Technical University of Cluj-Napoca.

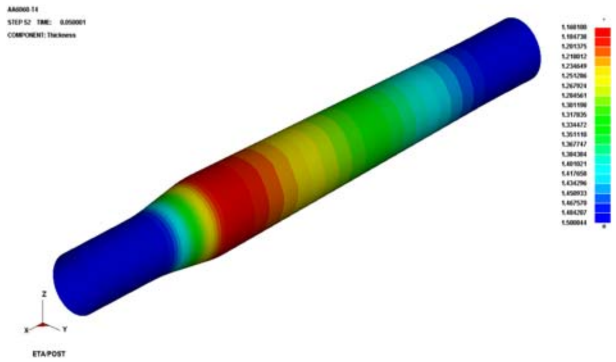


Fig.15 Thickness variation of the aluminium hydroformed part

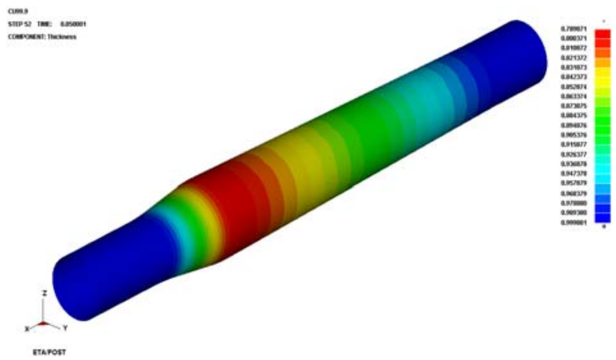


Fig.16 Thickness variation of the copper hydroformed part

Among the very useful information provided by DYNAFORM application there are the following:

- thickness variation in the hydroformed product;
- evaluation of risk of strangulation or breaking occurring in the part;
- influence of material parameters on the mechanics of the hydroforming process.

To perform the simulation, a 3D geometric model was created for the hydroforming mould of the tubular semi-finished product and for the plungers using SolidWorks software.

In DYNAFORM the moulds were assimilated to 3D rigid bodies (non deformable), and the tubular semi-finished product was modelled as a deformable 3D body.

Finite Element Method is an accurate instrument for studying the hydroforming process on tubular parts. For hydroforming simulation, the shell type finite elements are most suitable, as they are applicable to thin walled bodies.

Numeric results obtained from simulation will be compared with experimental data obtained in the laboratory.

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SIMULAREA NUMERICĂ A PROCESULUI DE HIDROFORMARE PENTRU UN REPER TUBULAR DIN STRUCTURA UNUI CADRU DE BICICLETĂ

Rezumat: Hidroformarea este un procedeu de fabricație tot mai atractiv atât pentru producătorii angrenați în domenii de înaltă tehnicitate, dar şi pentru producătorii unor bunuri de uz casnic. Această tehnologie utilizează presiunea exercitată de un mediu hidraulic pentru a produce deformații ale unui semifabricat sub formă tubulară. Hidroformarea tuburilor este o metodă din ce în ce mai mult utilizată pentru obținerea unor componente din structura bicicletelor, beneficiind de avantajul eliminării unor operații de sudură care necesită instalații costisitoare. De asemenea, raportul dintre caracteristicile de rezistență mecanică şi greutatea reperelor hidroformate este deosebit de favorabil, contribuid la reduceri semnificative ale greutății produsului.

Tudor Eugen MORAR, PhD Student,Eng., Technical University of Cluj-Napoca, Departament of Manufacturing Engineering, Muncii Bvd. 400641. Cluj-Napoca. E-mail: tudoreugen2000@gmail.com, Phone 0040 264 401731

Gheorghe ACHIMAŞ, Univ. Prof. Dr. Eng., Technical University of Cluj-Napoca, Departament of Manufacturing Engineering, Muncii Bvd. 400641. Cluj-Napoca. E-mail: Gheorghe.Achimas@tcm.utcluj.ro, Phone 0040 264 401731

Nicolae MIHĂILESC, PhD Student,Eng., Technical University of Cluj-Napoca, Departament of Manufacturing Engineering, Muncii Bvd. 400641. Cluj-Napoca. Phone 0040 264 401731

Sorin ACHIMAŞ, PhD Student,Eng., Technical University of Cluj-Napoca, Departament of Manufacturing Engineering, Muncii Bvd. 400641. Cluj-Napoca. Phone 0040 264 401731

Florin MOCEAN, PhD Student, Eng., Technical University of Cluj-Napoca, Departament of Manufacturing Engineering, Muncii Bvd. 400641. Cluj-Napoca. Phone 0040 264 401731