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Probabilistic approach to study the hydroformed sheet

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ABSTRACT
Under the leadership of the Kyoto agreements on reducing emissions of greenhouse gases, the automotive sector was forced to review its methods and production technologies in order to meet the new environmental standards. In fuel consumption reduction is an immediate way to reduce the emission of polluting gases. In this paper, the study of the formability of sheet submitted to the hydroforming process is proposed. The numerical results are given to validate the proposed approach. To show the influence of uncertainties in the study process, we take some characteristics of the material as random and the probabilistic approach is done. The finding results are showing the effectiveness of the proposed approach.

I. INTRODUCTION

Under the leadership of the Kyoto agreements on reducing emissions of green-house gases, the automotive sector is seen in the obligation to review its methods and production technologies in order to meet the new environmental standards. Deducted from the fuel consumption is an immediate way to reduce the emission of polluting gases [1].

Weight reduction needs have actually resulted in the introduction of new lighter shades in automotive structures. Thus, aluminum alloys have be-gun to be integrated into the structural parts of various vehicles. Besides aluminum, new grades of high-strength steel have also developed a specific offering mass resistance ratio better than conventional steels.

Reduce weight is not just about developing new lighter and more efficient materials but also reducing the number of elementary parts. Thus reducing the number of structural parts systematically causes the reduction of the raw material used, to weld or blank having only utility as that of the welding process requirements.

However, the production of complex geometries in a single piece is often not feasible with the conventional drawing process. Therefore, the hydro-forming process has been introduced as an alternative technology.

All hydroforming process technologies as diverse and varied, are based on the same principle, namely the operation of the action of a fluid under pressure to the shaping of a primary part that can be a tube, a blank or a double blank (see figure 1).

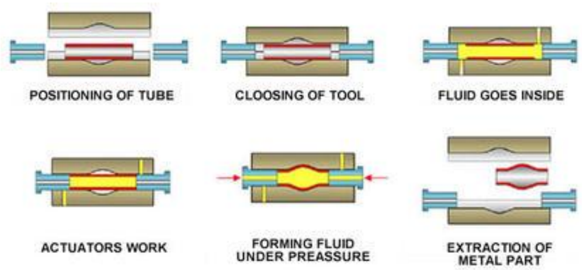

Figure 1: Hydroforming process

In the formatting process large deformations can cause irreversible dam-age mechanisms leading to strain localization before the break. To account for this phenomenon, several theories have been proposed to couple damage constitutive models. The most used approaches can be classified into two categories: damage formulation micromechanics, and the continuous damage models. The best-known examples of each category are the Gurson damage theory [2], and the mechanics of continuous damage [3]. The first approach is to describe the degradation of the material by means of an internal variable representing the volume fraction of microcavities formed during charging. We restrict the scope of uncoupled stresses to temperature or strain rate. However, modeling takes into consideration the effects of anisotropy and the large deformation.

The objective of this work is therefore to study the formability of sheet submitted to the hydroforming process. For this purpose, the circular section of sheet steel S250 is hydroformed in a circular section matrix using a hydroforming machine manufactured previously. Subsequently, the finished elements model is designed to simulate the hydroforming process. The influence of certain parameters, such as strain hardening, and the anisotropy of the coefficient of friction, on the thickness of the sheet in the section is analyzed. Our job is to analyze the process by a probabilistic approach taking into account the characteristics of the material.

II. Description of the hydroforming process

Hydroforming process is a method which has several recent innovative advantages over conventional forming methods. This technique is very effective to make complex shapes in a single operation. It is a technique that enables the production of metal parts, using a high pressure liquid to force a thin sheet or tube in a mold. The result can be a continuum that is extremely lightweight, strong and durable. Manufacturers can produce custom hydroformed parts on demand and can make generic parts for sale and mass distribution. Custom parts costs can depend on the size of the order and complexity. For the manufacture of specialized components, costs can be very high, because technicians may need to spend time on the development of technical specifications and plans before creating the mold [4].

A hydroforming technique uses a fluid-filled bladder. A technician places a flat sheet of metal on a mold and closing the mold, with the bladder by applying a pressure on one side. The technician increases the pressure, and the bladder forces the metal in the mold. When the technician opens the two halves, the formed part can be fully withdrawn. High levels of forms are possible with this method, and the metal can be very thin for light production techniques.

Another option is forming the tube. In this variant, the technician closes a tube within a mold having a cut somewhere along the length of the tube form and used to maintain the mold blocks in place. Then, the high pressure pumps technicians in the metal tube. The tube expands outwardly to accommodate the pressure and conforms to the shape of the mold. The technician can empty the tube and remove the mold, revealing a full game [5].

The costs of hydroforming may increase with large, complex molds. Technicians may need to experiment with the mold and the fluid to get the right level of pressure, which could require the manufacture of parts of several tests before moving on to the final production. For some components, fluidity and durability are worth the cost of hydroforming. Sector enterprises also constantly new techniques in development to reduce costs and increase reliability [6].

III. Problem statement

The behavior of the sheet is more often discussed in the context of an elasto-plastic approach for most forms of sheet forming processes. The elastic-plastic theory itself has two different approaches to describing each of them a physical scale behavior: the first is called phenomenological approach (or gross) and the second is called microscopic approach (or micro-macro model). The two approaches are intended to describe the evolution of the state of stress and strain in a succession of deformations.

The elasto-plastic behavior is based on a decomposition of the total apparent deformation in a reversible elastic part and a plastic part irreversible. When the elastic portion is small enough, it is common to adopt an additive decomposition of the tensor rate deformations:

$$\dot{\varepsilon} = \dot{\varepsilon}^e + \dot{\varepsilon}^p \quad (1)$$

$\dot{\varepsilon}^e$ and $\dot{\varepsilon}^p$ are the strain rate tensor, respectively, elastic and plastic. The total strain rate tensor is, in the case of small deformations, the symmetrical part of the tensor gradient of the velocity field V; which is written by:

$$\dot{\varepsilon} = 1/2(grad(V) + grad(v)^T) \quad (2)$$

The elasticity reflects a reversible deformation of the material. Most often, it is considered isotropic linear in the case of cold steel. In these conditions, the Cauchy stress tensor is connected to the elastic deformation rate tensor by Hooke's law:

$$\dot{\sigma} = 2\mu\dot{\varepsilon}^e + \lambda\, \mathrm{trace}(\dot{\varepsilon}^p) I \quad (3)$$

I is the identity tensor, λ and μ are the Lame coefficients derived from the Poisson's coefficient and the Young's modulus E by the following equations:

$$\mu = \frac{E}{2(1+\mu)} \quad (4)$$

And $$\lambda = \frac{E\,\nu}{(1+\nu)(1-2\nu)} \quad (5)$$

Therefore the potential state (Helmholtz free energy) is given by the scalar function of a convex containing the origin and a resilient plastic part:

$$\Psi = \Psi_e(\varepsilon^e) + \Psi_p(r,\alpha) \quad (6)$$

$$\sigma = \rho((\Psi_e)/(\Psi_e))R = \rho((\Psi_e)/r) \quad (7)$$

And $$X = \rho((\partial\Psi_p)/(\partial\alpha)) \quad (8)$$

The stress strain relationship is given by the known relationship as the generalized Hooke's law by the expression:

$$\varepsilon^e{}_{ij} = ((1+\nu)/E)\sigma_{ij} - (\nu/E)\Sigma\delta_{ij} \quad (9)$$

The Von-Mises yield criterion for determining the plastic yield point of an isotropic metallic material. The material is supposed to come into plasticity when its elastic shear energy reaches a threshold value. For a diagonal tensor of the constraints, the criterion of Von-Mises can be written as follows:

$$\sigma_{eq} = \sqrt{((1/2)[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2])} \quad (10)$$

So far it was only interesting in the form of the loading surfaces through plasticity criteria. However, throughout the loading, the sizes of these surfaces are changing: this is the plastic hardening. When the shape of the surface is kept unchanged and only changing its size, said hardening is isotropic and it is described by a curve of hardening.

The tensile test according to the rolling direction is often chosen as a test determining the work hardening curve linking the evolution of the yield strength (σ_0) to the internal hardening variable (ie the equivalent strain $\bar{\varepsilon}$ plastic). These curves are approached by analytical functions that can take several forms. In this paper, one considers the Swift law:

$$\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon})^n \quad (11)$$

IV. Numerical results

To study the formability of sheet submitted to the hydroforming process. For this purpose, the circular section plate 290mm diameter and 1mm thick steel S250 (E = 210000 MPa and ν = 0.3) is hydroformed into a circular section matrix. Thereafter, the finite element model is designed to simulate the hydroforming process.

The influence of certain parameters such as the coefficient of friction, Young's modulus and the Poisson's ratio of the total displacement of the sheet is done.

The finite element method is used to explore the strain and displacement as well as the influence of work hardening and the anisotropy of the sensitivity of these parameters on the response of the sheet. A three-dimensional model discretized finite element (3D) is then constructed with 15108 nodes and 7187 solids and then solved with the computational code ANSYS (see Figure 2).This is a sheet metal assembly and die dimensions and initial settings.

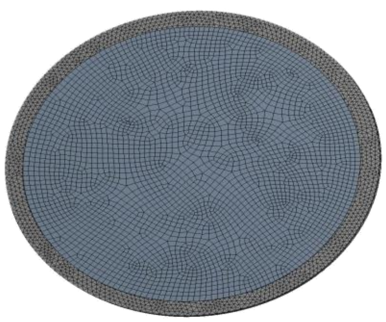

Figure 2: Sheet meshing

A surface pressure of 5 MPa profile over time is applied to the sheet surface. The sheet is inflated in the loading only releasing its ends in the direction of the axis of symmetry of the sheet. The behavior is formulated within the framework of anisotropic elasto-plastic models with isotropic hardening. The element of the sheet is considered a shell element. The contact between the sheet and the matrix is considered without friction.

4.1 Deterministic results

The choice of parameters for the simulation such as metal-matrix contact nature and the assembly of mesh type (metal-matrix) is paramount for the hydroforming process for it was considered a contact without friction (sheet - matrix) and a scan with shell element to the sheet.

Table 1 shows the variation in displacement according to the nature of contact between the die and the sheet

Table 1: displacement variation with contact type

Contact type	frictionless contact	Frictionally (μ=0.1- μ=0.2- μ=0.3)
Total displacement (mm)	33.355	33.187- 32.974- 32.962

To quantify the deformation and displacement of the plate we simulated: the equivalent elastic 0.000797 and 0.0187 and the displacement between 0 and 33.355 mm (Fig. 3).

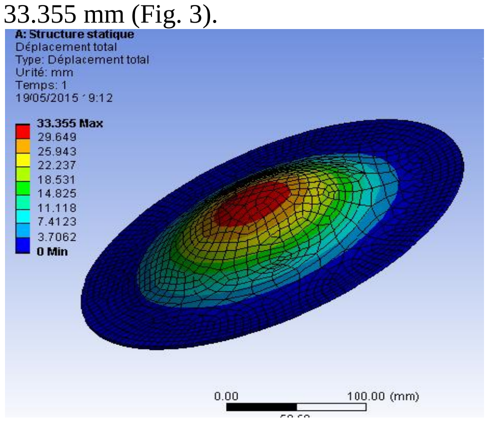

Figure 3: total displacement

4.2 Probabilistic results

Given the complexity of the problem, we have chosen to consider in this work that the sources of uncertainties in material properties, but the uncertainties regarding the other elements of the structure (geometry, boundary conditions and mechanical behavior) are not considered for reasons of simplification. The choice of standard deviations and the random variables means were selected on the deterministic and experimental analysis.

The standard deviations are also adjusted to maintain realistic ranges of materials involved. Table 2 presents the means of random variables and their standard deviations used in this study and the laws on selected distributions. The selected parameters are the Poisson ratio (0.3); the work-hardening coefficient (n = 0.2); Out of the coefficient (k = 460) and the Pressure (P = 5 MPa).

Variables	**distribution**	**medium**	**Standard deviation**
Poisson's ratio(v)	Gauss	0.3	0.015
Pressure (P)	Gauss	5	0.25
Coefficient (K)	Gauss	460	23
work hardening coefficient (n)	Gauss	0.2	0.01

Table 2: Variable Distribution

The context, the probability calculation was performed using a probability system design based on the Monte Carlo simulation (MC). For this last 100 samples were taken and the response surface method (RSM) 20 samples were taken. The table 3 shows the values of displacement after the probabilistic calculations with both methods: Monte Carlo simulation (MC) and the response surface (RSM).

statistical method	**Total displacement (mm)**
Monte Carlo simulation (MC)	Maximum calculated 38.401
Response surface method (RSM)	Maximum calculated 37.29

Table 3 : **Total displacement with statistical methods**

The curves of figures show the maximum variation in displacement relative to the Poisson ratio (v); the coefficient (K); the work-hardening coefficient (n) and pressure (P) with the method of the response surface (RSM).

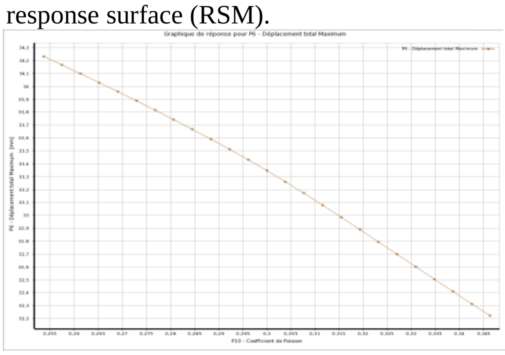

Figure 4: Variation of displacement with Poisson's ratio

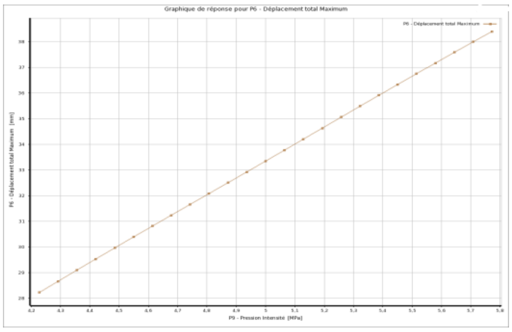

Figure 5: Variation of displacement with pressure

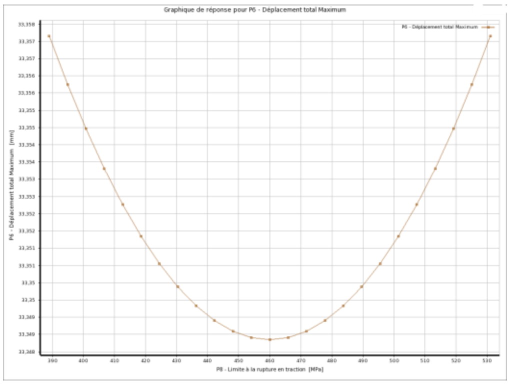

Figure 6: Variation of displacement with coefficient K

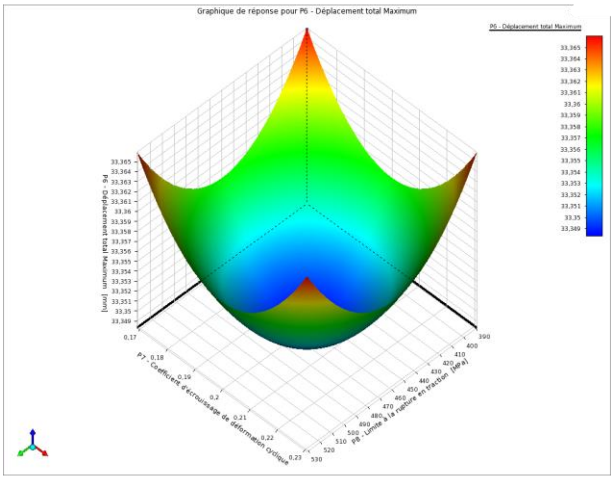

Figure 7: Variation of displacement with (K;n)

V. CONCLUSION

Modeling hydroforming is still a hot topic and its numerical simulation is a basis for adapting a best practice approach. The probabilistic approach allows taking into account the variation of the parameters that influence the process. It allows you to take advantage of reduced standard deviations related to the optimization of industrial manufacturing processes.

Based on numerical simulation to adapt a better approach to the contact between the die and the sheet (with or without friction), it was found that the choice of contact type proposed by ANSYS has had a good influence on the numerical results just as the choice of the type of finite elements of the plate.

Our next study is about the reliability analysis of some hydroforming process and to propose the good technic to compute the reliability index and deduce the failure's probability [7].

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