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FE simulation and full-field strain measurements to evaluate the necking phenomena

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Abstract

During airbag production, many parts are obtained by plastic deformation such as the lid of the gas generator. Since the airbag gas generator is a significant vehicle safety part, several pressure tests have been developed in order to prove the reliability of this product. A ductile fracture problem initialized by a localization of the deformation is observed along the blending radius. In order to understand the mechanical processes involved in the forming operation, a numerical and experimental study was developed. A tensile test specimen extracted from the sheet of study, undergoes elastic deformation that is followed by a transition to plastic deformation. Although during this stage of the test the deformation is stable, the strains begin to localize within a relatively broad zone known as diffuse necking. The stable deformation, with continuously rising load, is followed by the instability whereby a local neck or shear band is produced due to strong localization of deformation. The localization is explainable by the inhomogeneity in macroscopic material properties in the specimen. The necking behavior is a vital precursor to the final failure. A Digital Image Correlation (DIC) method is used in 2D and 3D to evaluate the necking and localization of deformation, which shows clearly the two stage of necking phenomena. Moreover, a numerical modeling was developed of tensile test under ABAQUS commercial software. In this model we use Gurson Tvergaard Needleman (GTN) ductile model of damage to predict the necking phenomenon. Furthermore the results from FE simulations are compared with experimental results from uniaxial tensile tests. Finally we develop the numerical model of the lid of the gas generator obtained by forming process.

Keywords: Metal forming, local necking, diffuse necking, tensile test, FEM, DIC, ductile damage;

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1. Introduction

Airbags, like safety belts contribute greatly reducing the death rates on the roads [1]. Some pieces of airbag are obtained by metal forming. The occurrence of defects in sheet metal forming is an important problem for mass production (i.e. automotive industry). In this context, many methods have been developed in order to identify the mechanical behavior of thin ductile sheets. The standard tensile test is one of the most important engineering procedures used to characterize the mechanical behavior of materials. This simple test provides the intrinsic stress-strain relationship during a uniform loading history up to a certain point. In the deep drawing process, the metal used for manufacturing is selected according to the formability deduced from the forming limit diagram (FLD). Generally, this FLD is computed from a plastic theory and necking conditions. This latest phenomenon is considered as a vital mechanism for fracture prediction in forming processes. When a sheet is increasingly thinned, two different plastic instabilities appear: diffuse and local necking. In 1885, Considère proposed the first criterion of diffuse necking suitable for uniaxial tension which is related to the maximum force. Concerning the industrial point of view, during the processes of airbag production, many parts are obtained by plastic deformation, as for example the lid of the gas generator illustrated in figure 1. Since the airbag gas generator is a significant safety part in automotive industry, many pressure tests have been developed in order to prove the safety of this product. These tests involve a dynamic internal pressure loading that can be finished by a fracture in bending radius zone. In several cases, a ductile fracture problem initialized by a localization of the deformation is observed along the sensitive area. In order to understand the mechanical behavior involved in the forming process, an experimental study has been conducted to identify the material properties of the S360 steel.

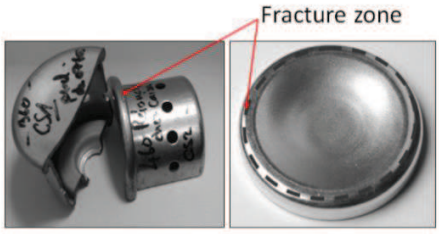


Fig. 1. Example of S360 steel application: the lid of gas generator of airbag

2. Experimental investigation

2.1. Digital Image Correlation and Stereo-correlation

In order to obtain a measurement out of plane, a 3D image correlation technique (stereo correlation) is used. On the surface of specimens, a random pattern is developed using white and black paints, two calibrated cameras are used to record two images of the undeformed surface and two images of the deformed surface. The SIC analysis by Aramis software based on the calculus of the matrix which relate the coordinates system of the two cameras. Fig. 2-a show the configuration of the two camera points P1 and P2 used to calculate object point P (x,y,z) in the tensile sample. Example of the results of stereo image correlation (SIC) is presented in Fig. 2-b.

Digital Image Correlation (DIC) is one of the most important non-contacting methods to measure full-field displacement. Full-field displacement and strain measurements are widely used in laboratories conditions and for experimental applications in industries. These techniques are summarized in acquire images of an object, store image and analysis to extract the local displacement. Principally, 2D Digital image correlation can be used to measure displacement and strain fields of planar surfaces. The setup of this technic inquires only one camera, where the displacement is obtained by comparing the random pattern of grey levels in two images during forming.

During the tensile test, two cameras are operating separately, the first one is fixed in front of tensile sample while the second is positioned to measure the displacements filed in the profile view as shown in Fig. 3-a.

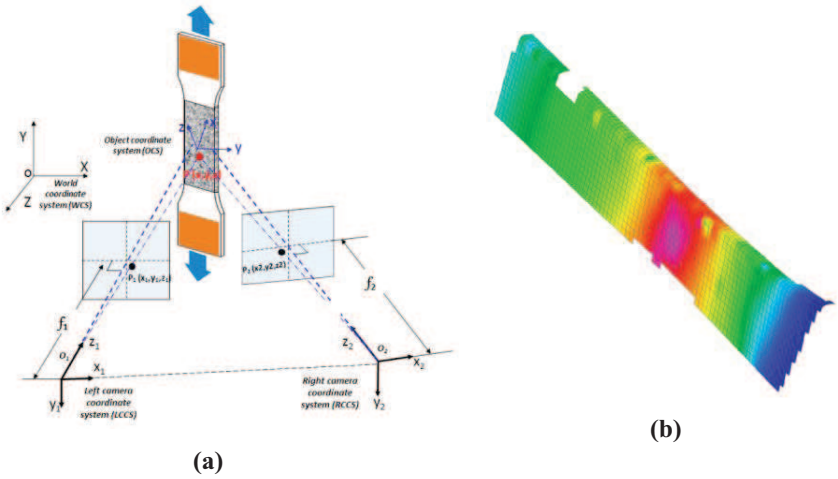


Fig.2. (a) Stereo correlation principle, (b) Example of stereo correlation results.

2.2. Tensile test

In the first section of this paper, we presente an experimental work to characterize a deep drawing steel S360 used in airbag part production. The determination of the displacement and deformation field is carried out by images correlation. Fig. 3 describes the geometry of specimen and the experimental procedure and illustrates the equipment used during these tests. Control and data acquisition is performed by computer interfaces and commercial software. Two different configurations are used as presented in previous sections.

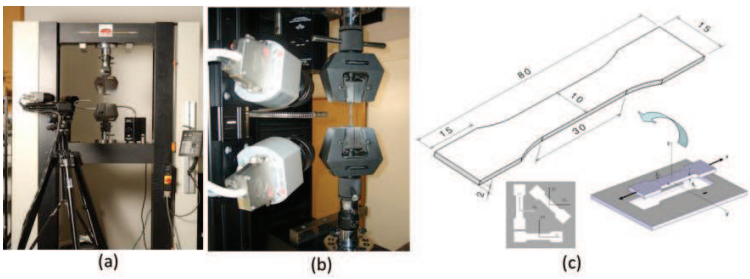


Fig.3 (a) tensile test with cameras in position 1, (b) stereo correlation position, (c) tensile test specimen geometry

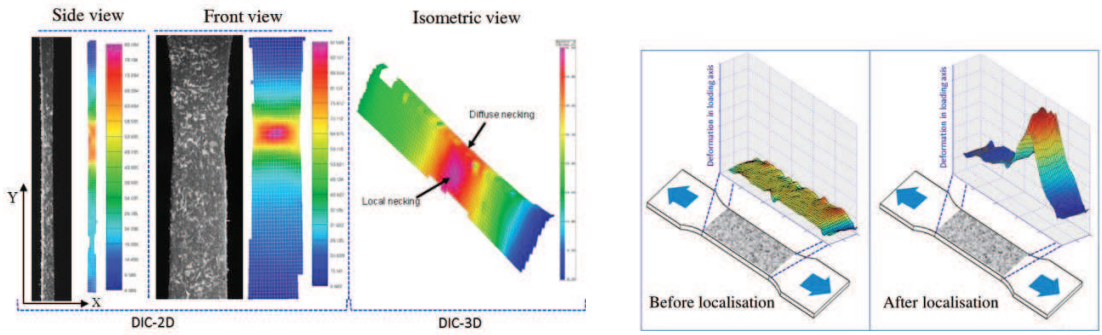
The direct result acquired during tensile test is the variation of force according to the displacement. Then this relation is usually changed to one between the true stress and the true strain and this later is used as the hardening law. In this work, to identify the S360 deep drawing steel, in order to determine the stress-strain curve, two virtual sections are selected in the central zone of the surface of the initial specimen and the relative displacement of these sections is tracked during the loading process to compute the strains for all the digital images captured by the cameras. The hardening material parameters have been identified, with respect to the Swift equation:

$$\sigma = K(\varepsilon_0 + \varepsilon)^n \qquad (1)$$

where K is the strength coefficient, n is the strain-hardening exponent and ε_0 is a pre-strain. The experimental value of ε_0 is very small and could be calculated from the values of K and n, (K=741.3, n=0,174, ε_0= 0,017).

2.3. Necking study

Fig. 4, show the necking formation that develops starting from a certain level of deformation. Two phases of necking are visible in the successive digital images of the sample surface during the tensile test on the DIC results computed by the Aramis software. The necking evolution starts by a symmetric diminution of the width of the specimen. This one is called the diffuse necking. If the last phenomenon is preceded, the severe thickness reduction that mainly takes place at the center of the sample causes a sudden initiation of a crack that immediately propagates in an unstable form along only one shear band. This later is called the local necking. In figure 4-b, we observe that the deformation is quickly heterogeneous in the tensile direction. For a given value of the load, there are several values of the strain in the sample surface.



(a) (b)

Fig. 4 Tensile test results: (a) DIC results 2D and 3D, (b) 3D curve of deformation in the spesemen surface

3. Finite elements simulation

A Finite Element Method applied to predict some phenomena such as necking. In this model we consider a material elasto-plastic behavior with ductile damage type modified Gurson. The Gurson-Tvergaard-Needleman (GTN) approach model the different stages of damage evaluation in material. The yield function describing the plastic constitutive model is represented as flows:

$$\varphi(\sigma,\sigma_m,f)=\frac{\overline{\sigma^2}}{\sigma_y^2}+2f^*q_1\cosh\left(\frac{3}{2}q_2\frac{\sigma_m}{\sigma_y}\right)-(1+q_3(f^*)^2)=0 \qquad (2)$$

Table 1. GTN model parameters used in numerical modeling

f_0	q_1	q_2	q_3	ε_N	S_N	f_N	f_F	f_c
0.001	1.5	1	2.25	0.6	0.1	0.04	0.12	0.1

All required parameters for this numerical modeling presented in table 1. Fig. 5 shows the results of numerical model that a good correlation was observed with the experimental results.

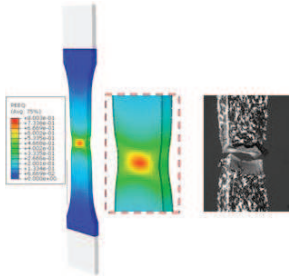


Fig.5 Necking in tensile test obtained by FEM with GTN damage.

After determination of 360S steel behavior and validation by tensile test a numerical model of the manufacturing of the lid of the gas generator was developed .Fig. 6-a show the tools used in the forming process and Fig 6-b show the numerical results. The critical deformation and damage localized in the bending radius where we observed the crack during destructive test.

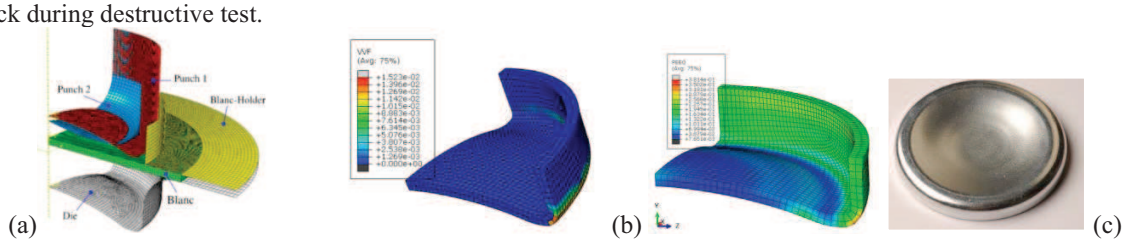


Fig. 6: Airbag parts obtained by metal forming numerical simulation: volume fraction distribution (WF), Plastic distribution, distributing and real piece

4. Conclusions

The aim of this work is to characterize S360 deep drawing steel used in automotive industry, study of the necking phenomena and the material formability. A Digital Image Correlation (DIC) technique in 2D and 3D are used in the experimental investigation. This advanced measurement system is used for reliable identification of the mechanical behavior of sheet metal by tensile tests. Moreover, a large study of diffuse and local necking and the evolution of this phenomenon are carried out. The material behavior law assumed to follow the Swift hardening law and a damage ductile model type Gurson used to predict the experimental test results using FE method. DIC and SIC contribute greatly to understand some mechanical material behavior present during mechanical loading especially in the localization of deformations. The numerical modeling of mechanical test shows a good correlation between numerical and experimental results. A virtual manufacturing process of airbag part was developed under Abaqus software that shows the critical damage in the bending radius where it observed the fracture during the destructive test.

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