Simulation and Experimentation of Micro-single Point Incremental Forming Process of Thin Sheet Metals

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Abstract :

Incremental sheet forming is a rapid prototyping process which used a forming tool to form a sheet metal according to a predetermined trajectory of tool controlled by a CNC machine. This article is dedicated to the study of the Single Point Incremental Forming (SPIF) process and more particularly to the numerical simulation of a pyramidal shape with the finite element calculation code ABAQUS/Explicit and in the validation of these numerical predictions using the results of experimental tests. In addition, force profile comparisons made during an incremental forming operation revealed a good correlation between the numerical simulation and the experimental.

Keywords : Incremental forming, numerical simulation, ductile damage model.

1 Introduction

Incremental sheet forming is a new technology allows to obtain complex parts using a hemispherical end tool by applying a locally deformation process in sheet metal. The desired geometry is provided by using a specific forming tool path controlled by a CNC machine. The main advantage of this process is the very low cost of tooling development compared to conventional processes as deep drawing [1].

A second asset of this process is due to the important plastic strain level that it can be obtained. The main objective of this work is to develop a numerical tool by applying a GURSON-type ductile damage model with the finite element calculation code ABAQUS/Explicit and validating these numerical predictions using the results of experimental tests.

For the behavior model, A micromechanical GTN’s model is chosen for the prediction of the damage and ductile fracture of materials which is based on the model initiated by Gurson [2]. In its basic form, the Gurson’s model represents only porosity growth to quantify material degradation during loading.

Later the Gurson's model extended by Tvergaard and Needleman [3] by adding new parameters of damage to the expression of the yield surface and by the introduction of nucleation and the coalescence phenomena. With these modifications an extension of the Gurson model appeared, define as the GTN's model and it is expressed by

$$\phi = \left(\frac{\sigma_{eqv}}{\sigma_y}\right)^2 + 2q_1 f^* \cosh\left(-3q_2 \frac{\sigma_m}{2\sigma_y}\right) - \left(1 + \left(q_1 f^*\right)^2\right) = 0$$

Where σ_{eqv} is the von Mises equivalent stress, initially equal to σ_0 (initial yield stress), σ_m is the hydrostatic stress, and q_1, q_2 are the Tvergaard's coefficients and the function $f^*(f)$ defines the void volume fraction in GTN's model.

The material is modeled by the von Mises yield function and Voce's isotropic hardening law [4], for the description of plastic evolution.

$$\sigma = \sigma_y + Q\left(1 - exp(-b\varepsilon^p)\right)$$

Where σ_y is the initial yield stress, Q saturation value of isotropic hardening, b is the hardening exponent.

A copper alloy material is considering with a controlled grain size [5]. The comparisons made on the force prediction during a single-point incremental forming (SPIF), operation of a pyramidal shape (truncated) [6], and the results obtained, revealed a good correlation between the numerical simulation and the experimental.

2 Experimental methods

2.1 Material : tensile test

For this study, the selected material is a square copper alloy sheet Cu-0.1Fe with an initial thickness of 0.21 mm and initial hardness of 124 HV. The elastic parameters are 100 GPa for a Young modulus and 0.31 for the Poisson ratio. The material is annealed at 400°C for 30 min to eliminate the effects of rolling texture and to make the structure homogeneous [5].

Uniaxial tensile tests were conducted on flat specimens in three directions : 0°, 45° and 90° with respect to the rolling direction. The stress-strain curves are presented in fig.1.

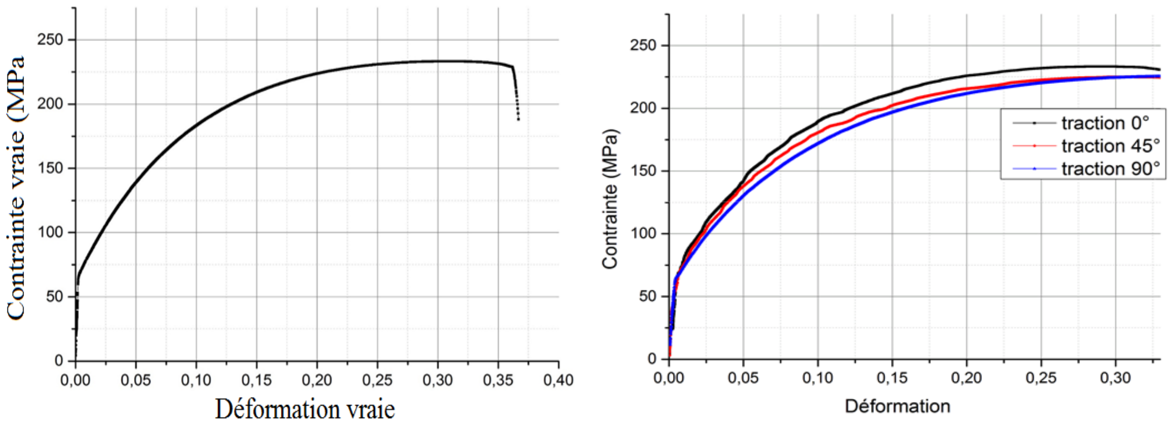


Fig.1. true stress-true strain curves

The main mechanical properties of the material are done in Table 1.

Table 1
Mechanical properties of Copper alloy Cu-0.1Fe

Density ρ (g/mm^3)	**8.92 E-9**
Young modulus E (MPa)	**128 000**
Poisson ratio ν	**0.31**
Yield stress σ_y (MPa)	**67**
Hardness (HV)	**124**

2.2 Incremental sheet forming process

An experimental device used as a platform for the deployment of single-point incremental forming (SPIF) process, is mounted on a CNC milling machine as shown in Fig.2a. It consists of several elements: die support, modular die and blank-holder clamp for fixing the sheet metal on its contour. This device holds the sheet metal in position during the movement of the forming tool.

Simple tool with hemispherical heads with a radius of 1.9 mm, adapted on the vertical axis of the machine CNC, is used as forming tool. In this study, a pyramidal shape of the finished part is considered by the generation of trajectory in an integrated environment of CAM (Computer Aided Manufacturing) package (fig.2b). During the forming operation, the movement of the tool is in the Z direction while the sheet moves simultaneously with the table in the plane (XY). In order to reduce friction behavior of the tool and workpiece and improve blanks formability [7], a grease was used as lubricant.

The size of the sheet metal part used in incremental forming is (34×34) mm2. It is clamped around its contour with simple clamps. The blank holder has a (6×6) mm2 square orifice where the blank could be formed.

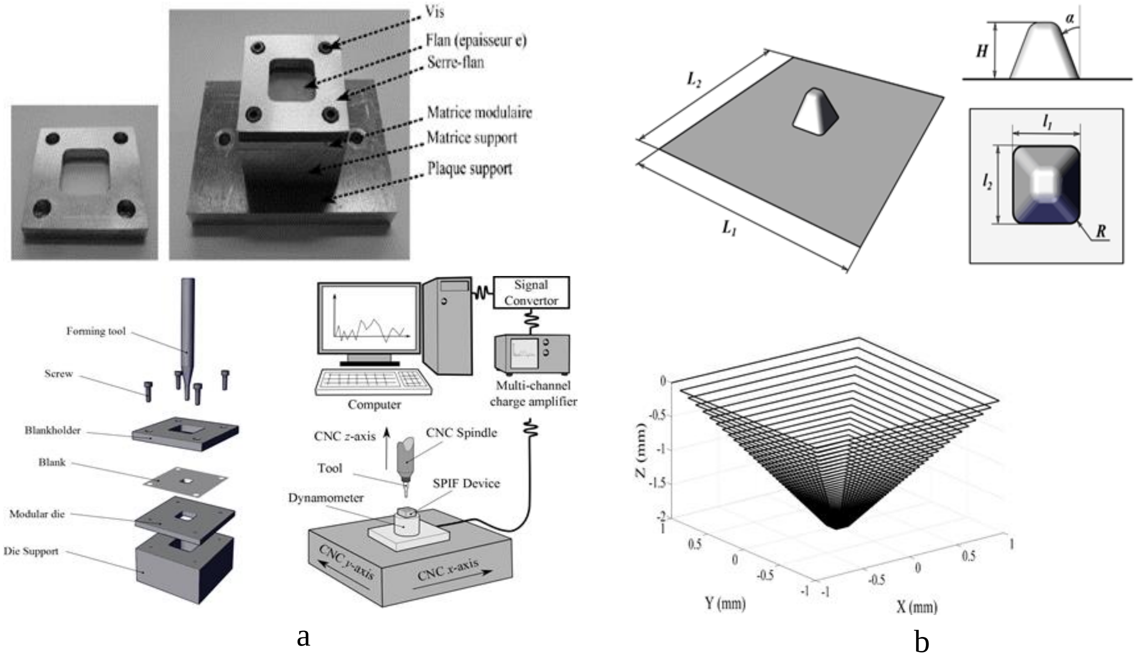


Fig.2. Micro-SPIF test: a-Testing device, b- geometry and forming strategy

3 Numerical methods

The finite element method is chosen to simulate the process, with the same geometric from the experimental study for a pyramidal shape, fully integrated eight node solid elements (C3D8) were used for the blank, in order to get information on the thickness evolution. Three elements in thickness are considered, the rest of the tooling (Tool, die support, modular die and blank-holder), with rigid shell elements of type R3D4. The complete mesh size of this automatically obtained study is presented in Fig.3.

The simulations were performed with the ABAQUS® software using four processors. The total calculation time is 15 hours per simulation. The evolution of process as a function of the forming cycle is shown in Fig.3.

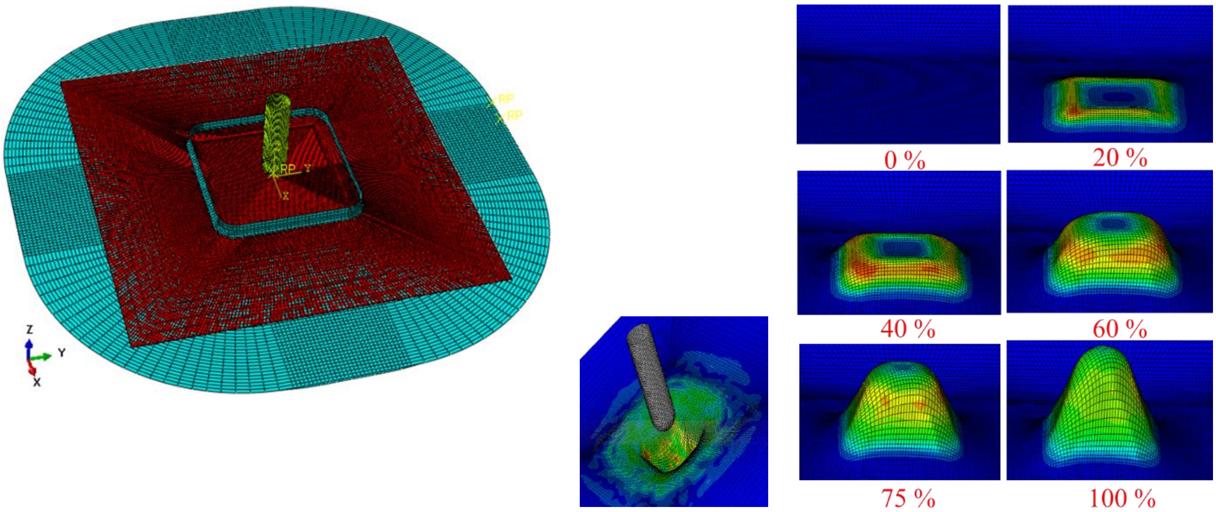
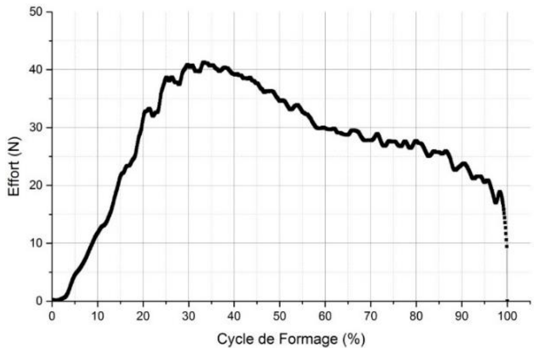


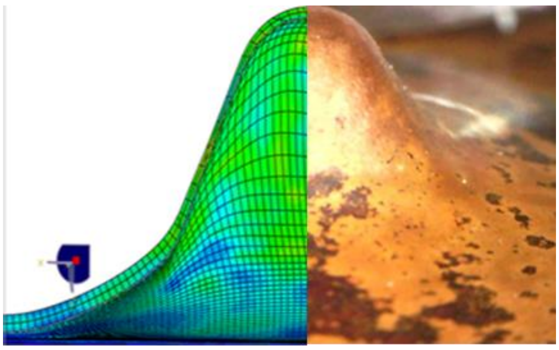
Fig.3. Modèle EF du micro-SPIF

a



b

Fig.4. Micro-SPIF test : a-Pyramidal form, b- Forming force



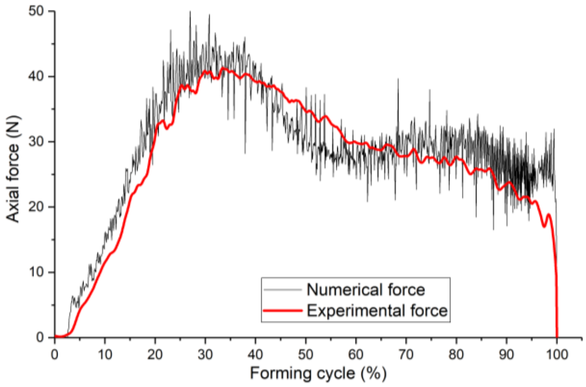


Fig.5. Numerical and experimental comparisons results: Geometry and Forming force

4 Results and conclusion

The work reported above has demonstrated the ability to predict correctly the materials behavior during the single-point incremental forming process SPIF. A micromechanical GTN model is chosen for the prediction of the damage and ductile fracture of materials applied to a single-phase copper alloy (Cu-0.1Fe). In a second step, experimental tests of this process were carried out in order to study the mechanisms involved in Figure 1.

The geometry and axial force results show a good correlation between the experiment and the numerical predictions for a pyramidal form (Figure 5). This comparison was very satisfactory and allowed us to validate our approach.

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