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Finite element analysis and experimental investigations for improving precision in single point incremental sheet forming process

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ABSTRACT: As it is well known, the design of a mechanical component requires some decisions about tolerances and the product has to be manufactured with a careful definition of the process set up. Although standard sheet metal forming processes are strongly controlled, new processes like Single Point Incremental Sheet Forming remain to be improved. In SPIF, the final geometry is generated by the envelopment of all positions assumed by a simple forming tool which deforms a clamped blank. No dies are required differently than any conventional sheet metal forming processes. Although ISF concept allows to increase the flexibility and to reduce set up costs, such a process has a negative effect on the shape accuracy by initiating undesired rigid movement, elastic springback and sheet thinning. This paper emphasizes the necessity to control all process parameters to improve final shape accuracy. To attend to this aim, a finite element analysis is performed in order to study the influence of forming strategy on the opening or the closing of rings taken from a truncated cone manufactured by SPIF. The results obtained allow to have a better knowledge of springback effect on parts manufactured by SPIF with the aim to improve their accuracy.

Key words: Single Point Incremental Sheet Forming, FEM analysis, Forming strategy, Elastic springback, Sheet thickness.

1 INTRODUCTION

In the modern manufacturing world wide scenario, the requirement of customized production, cost reduction, life-cycle shortening is still growing. Scientists have to find answers to these urgent requests and new technologies seem to be a sustainable approach to reach such aims in all sectors of activities including sheet metal forming.
Thanks to a basic concept different than conventional metal forming processes, the introduction of incremental forming may represent a progress in the manufacturing processes evolution [1]. In Single Point Incremental Forming, the final geometry is generated by the movement of a simple punch controlled by a CNC milling machine which deformed a clamped blank. This concept allows to avoid the use of traditional die differently than conventional stamping processes.
Regarding the concept of such a technology, a set of advantages provided by SPIF can be listed. Incremental forming technology allows to reduce set-up costs significantly [2-3] and presents a very high flexibility. Furthermore, due to the favourable stress state induced by the punch during the local deformation, the material formability is higher in comparison with conventional stamping operation [4].
As SPIF is an emerging process, it remains to be improved to make an industrially suitable process. In this sense, it is very important to increase the knowledge of such a technology through both experimental and numerical investigations. Therefore, this paper is based on an accurate FE analysis of the process used to emphasize the necessity to control all process parameters in order to make an industrially suitable technology. The forming strategy is taken as example to underline its influence on the formed part.

2 MODELLING AND NUMERICAL ANALYSIS

2.1 *Finite Element Model*

In recent years, Finite Element Analysis has been considered to be an effective tool for simulating

such an emerging metal forming process. As incremental forming is a progressive sheet metal forming process characterized by large displacements and localized strains, an explicit solution scheme was adopted, resulting in the choice of LS-Dyna® as the FEM simulation code. In a next section, elastic springback simulation of formed part is running by adopting an implicit scheme.
According to previous experimental investigations [5], the investigated shape to perform simulation is a truncated cone. Main data are summarized in Table 1.

Table1. Dimension of the investigated shape

Major base	140mm
Minor base	40mm
Depth	50mm
Wall inclination	45°

Due to the three-dimensional tool path, a fully three-dimensional analysis is required. As a consequence, shell elements with 4 nodes and 6 degrees of freedom per node and five integration points along the thickness were used. These are reduced integration elements (one point in the plane). Furthermore, an adaptive mesh refinement, which allows four levels of refinement, was performed in order to reduce element size when the distortion level reached a maximum value. These ingredients allow a proper modelling of the progressive deformation of the sheet by increasing the number of nodes in contact with the tool surface. The sheet was initially meshed with 3600 elements.
The 10 mm diameter tool head is considered as a rigid body and the corresponding boundary conditions are related to the path that it should follow during the process.
Sheet metal behaviour over the yield stress has been accounted by means of a Swift type hardening law:

$$\bar{\sigma} = k.\left(\varepsilon_p + \bar{\varepsilon}\right)^n$$

Parameters were defined through results of sheet bulging test. Material used in this study is an aluminium alloy 1050.

2.2 *Results and discussion*

2.2.a. Analysis framework

In order to validate the numerical model, the final shape was measured offline and compared with numerical ones. A set of several series of measurements taking into account the transverse sections highlighted in Figure 1 was performed. As results demonstrate that the part is properly formed and maintains its symmetry, next sections will focus on the zone AB where the tool has its vertical displacement.

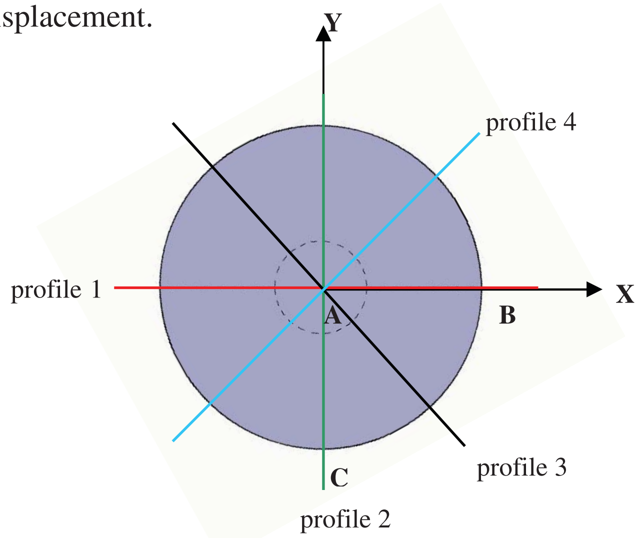

Fig. 1. Definition of profiles used in measurement.

The tool path is made up of a series of rotational movement around the vertical axis of the milling machine generated transverse to the long axis of the cone. Once the rotation is done, the tool moves in horizontal direction and penetrates the blank in the vertical direction to follow the next contour (Figure 2).

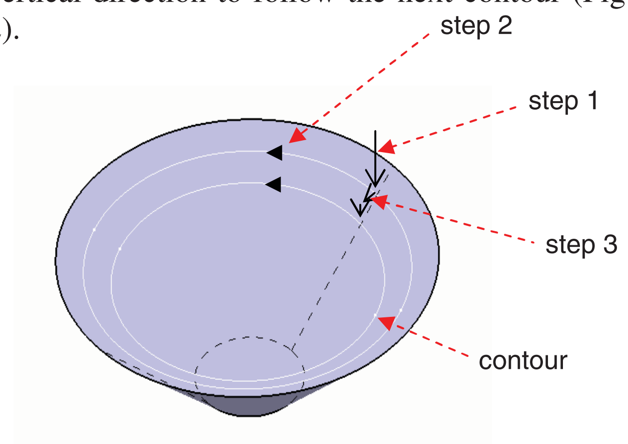

Fig. 2. Forming strategy used in experimental measurement – Tool path A.

From this modelling, a numerical study was performed to observe the potential relationship between the tool path and geometric defects due to elastic springback. Two strategies in simulating the SPIF were deployed. In the first one (strategy A) the followed tool paths in both the simulation and the experiment are equal, whereas in the second strategy (strategy B), the simulated tool path alternates in clockwise and counterclockwise direction.

2.2.b. Strain history and distribution

In order to study the influence of tool path on the strain history, the strain path was analyzed for the elements indicated in Figure 4. During simulation, the selected elements were consecutively affected by the tool movement. Element 4191 was located in the bending zone, close to the major base of the cone. Elements 4215, 4239 and 4263 correspond respectively to a depth of 15mm, 30mm and 45mm. These elements are located along the section AB of the profile 1 (Figure 3).

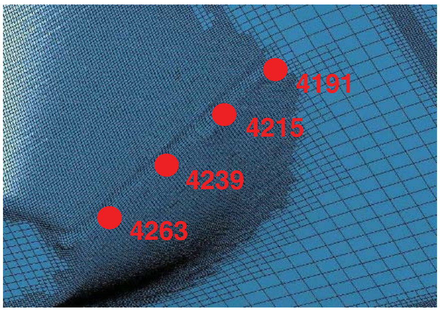

Fig. 3. Location of elements along profile 1 in strain analysis

As it has already been underlined in previous studies [6], figure 4 shows increments which characterized the strain history of elements in ISF.

Regarding the influence of the forming strategy on strain history, it can be noticed that the effective plastic strain value obtained with tool path B is lower than the one obtained with strategy A. Indeed, the relative variation between the two strategies goes from 13% for element 4191 to 19% for element 4239.

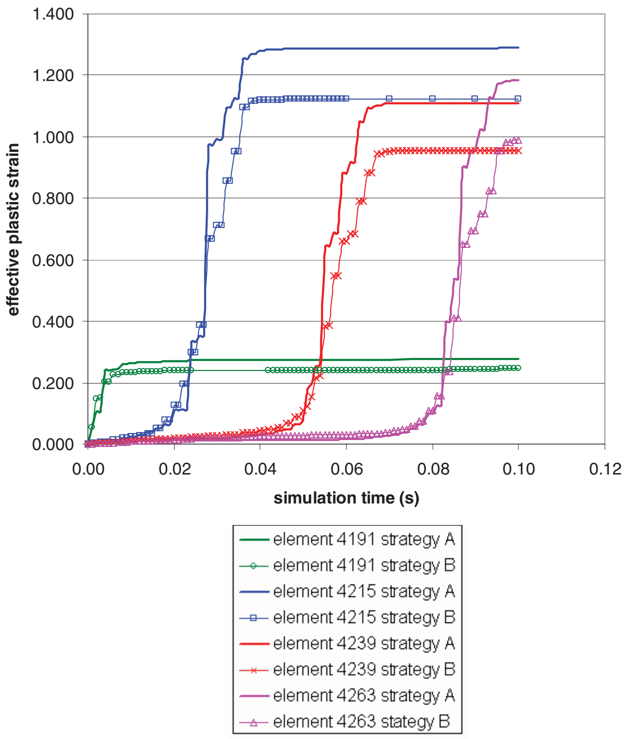

Fig. 4. Strain history along profile 1.

So, from observations made on global aspect of experimental parts manufactured by ISF using strategy B, this first analysis emphasizes the influence of the forming strategy on the strain distribution and represents a first remark which has to be taken account to improve the quality of the formed part.

2.2.c. Thickness measurements

As incremental sheet forming is mainly characterized by stretching deformation mode of the sheet metal added to the lack of any dies, a significant sheet thinning determines accurate limits of the process.

The numerical analysis has demonstrated that the used of strategy B allows to reduce the local sheet thinning of the zone AB by up to 8% (Figure 5).

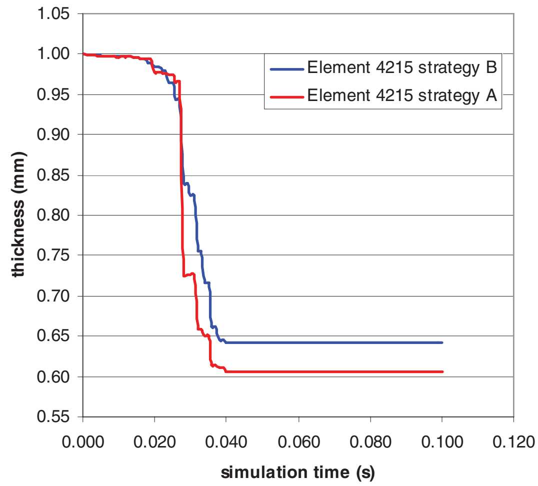

Fig. 5. Influence of tool path on thickness history.

To conclude on this section, the analysis of thickness distribution and strain history emphasizes the necessity to control all process parameters to improve final shape accuracy by showing directly the influence of the forming strategy on the formed part.

2.3 Elastic springback analysis

Problems of dimensional accuracy on parts formed by ISF due to elastic springback effects are well known. The next section deals with an original way to analyze this mechanical effect by focusing on the influence of tool path localized in the wall of the cone [7].

The elastic springback analysis is obtained from rings taken from the formed part as it is shown in Figure 6.

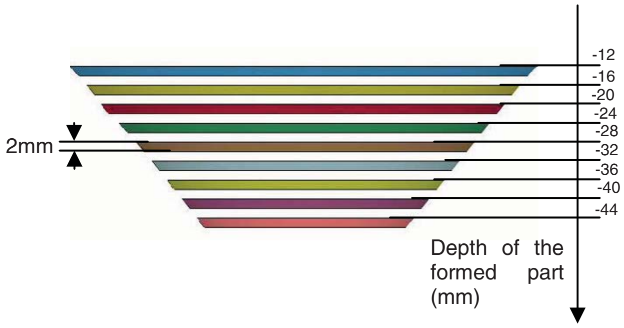

Fig. 6. Location of rings taken from the formed part at different depth.

Each ring is cut along an axis. Nodes which are localized on the opposite axis are completely constrained to allow the prediction of elastic springback and to avoid rigid movement in the prediction phase.

Elastic springback is characterized by closing of each ring with a bigger gap in the horizontal plan of rings -20/-22, -24/-26, -28/-30 corresponding at the middle of the wall.

Figure 7 shows that nodes which are initially joined deviate from each other in X direction with a bigger opening in the case of strategy A than in strategy B, contrary to in Y direction, a bigger closing is obtained with strategy B.

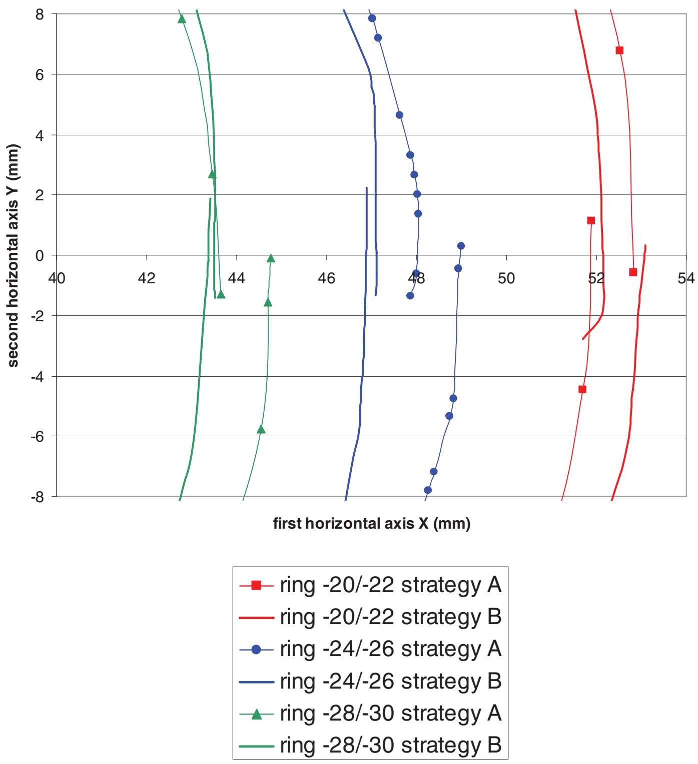

Fig. 7. Tool path influence on elastic springback of rings localised in the middle of the wall of the formed part.

3 CONCLUSIONS

As it is well known, incremental sheet forming process is a very promising manufacturing process which still requires further optimizations. Numerous studies have demonstrated the effect of process parameters like advancing speed, forming force, tool depth step in the characteristics of the formed parts. This paper added knowledge on the influence of the forming strategy on the formed parts not only on a geometrical point of view, with an original elastic springback analysis, but also on the evolution of strain and thickness distribution, showing the possibility to improve the quality of the final parts by an accurate control of all process parameters. In the one hand, such an improvement is directly linked with the use of optimised tool trajectories. In the other hand, a better knowledge of experimental evolution of the characteristics of formed parts during the process is necessary to go farther with the aim to make an industrially suitable technology.

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