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Validation of the computer simulation process applied to the incremental forming process for the evaluation of strain paths

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Abstract. In recent decades, the forming area advanced both in terms of material used as well as in flexibility and process cost reduction. New processes are been studied, including the Incremental Sheet Forming – ISF. The ISF is a process characterized by the production of small batches of parts, rapid prototyping, and manufacturing flexibility with reduced operational cost. This study aims to compare the computer simulation with real experiments from ISF. The results of strain paths of the three main strains simulated were consistent with the experimental manufacture of a symmetrical sample.

Introduction

The conventional processes are the ones that produce the metal sheet forming, using a tooling in a press, mainly for mass production. As examples of part line, there are automobile bodies, white line appliances, and other products (e.g. computer carcasses, home utensils, etc.).

ISF is basically directed for the production of small batches of parts, rapid prototyping, and great process flexibility with reduced operational cost. The cost reduction is focused on the lack of demand of manufacturing a high cost metal die, in other words, it is possible to have a die with reduced costs, to be partially applied to the process. The ISF method happens using the point load application to the metallic sheet, causing incremental strains. This type of strain applied to the piece causes large material strains, which are much superior to the strains of the conventional processes [1,4].

The computer simulation is one of the tools that engineering can use to forecast errors, manufactured part final geometry, tensions... This paper also evaluated the use of a commercial software to validate the incremental stamping process, using the strains path and their final geometry.

1. Literature Review

The process of incremental stamping includes the application of force using a punch in the metal sheet, making punctual strains. The sum of the strain points determines the final geometry of the part.

The types of incremental processes applied to the metallic sheets can be classified according to the direction and movement of forming system (sheet, punch and die).

1.1. Spinning

In this process, the metal sheet is attached to an axis that allows its angular movement, where the punch applies incremental punctual force (Figure 1).

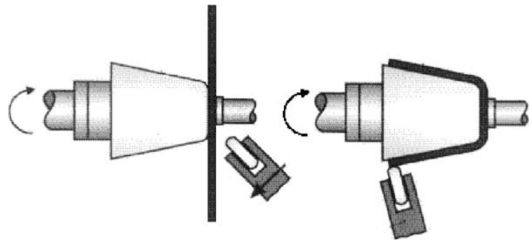

Fig. 1. Spinning [5].

This process is applied to round parts and, whenever needed, temperature can be used to increase the drawability of the material. An example of the equipment applied for this process is the one called “turning lathe”, where the sheet is attached to be able to spin around its own axis.

Other references [6] emphasize the spinning process because it is widely used in small factories, such as the ones found in the metropolitan region of Salvador-Bahia-Brazil [7].

1.2. **Incremental Stamping Process**

With the incremental sheet forming process, a metal sheet with a varied geometry is attached to a sheet-press and is shaped using a continuous punch movement with a circular shape on the end.

The metal sheet forming is done using a tool that runs along a series of contour lines that move in horizontal and vertical directions. The movement described by the tool may be variable, as a continuous helical or cycling, gradually altering the geometry.

The equipment used to do the procedures can define the type of process, where there are specific incremental stamping machines, Machining Center, and/or Robots. Figure 2 shows the application of three types of equipment in the incremental stamping process.

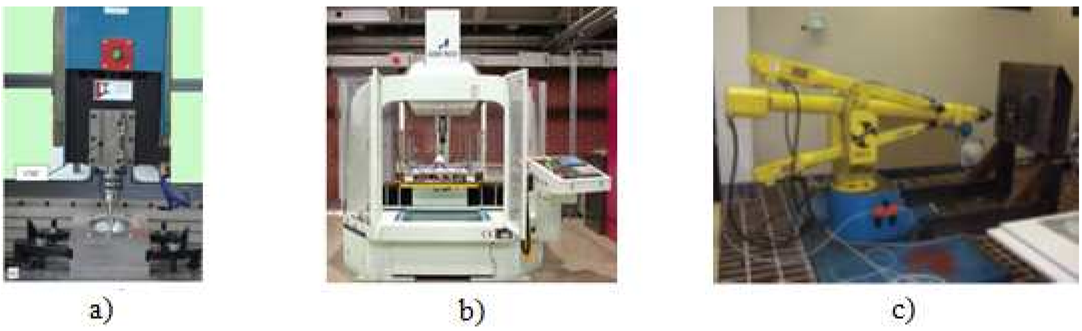

Fig. 2. Use of equipment in the incremental process. a) Milling Center [8]; b) Specific for the process [9]; c) Robot [10].

The application of machining centers in incremental sheet forming is the oldest method, with easier programming of tool movement when compared to other equipments [11,12]. The specific ISF machines, such as the AMINO DLNC-RB of the Institut für Bildsame Formgebung of Rheinsch-Westfälische Technische Hochschule in Aachen, Germany, are different from the machining centers where the equipments have their proper bases for the attachment of sheets during the processes. The use of robots is due to their major movement flexibility, otherwise their programming is more complex.

The incremental stamping processes can be classified as: SPF – Single Point Forming and TPF – Two Point Forming, where TPF has total or partial support. Also, a determination method can be used for the types of processes that are applied, such as Negative of Positive. These types of processes can be seen in Figure 3. The application of negative force is inside the cavity to be formed, and positive force is applied to the external part of the cavity.

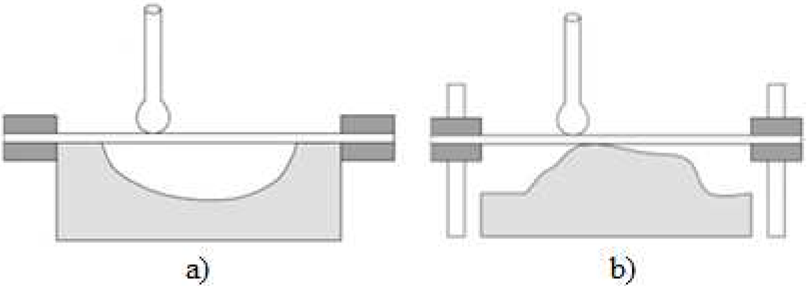

Fig. 3. a) Negative Process; b) Positive Process [15].

The Positive process always happens in the TPF process, where it is necessary to have a base (die) that is located inside the part – this is because the punch force in done in the “convex” part of the part, making the contour lines. The Negative process may be applied to both processes, depending of the project characteristics.

The classification of the processes in SPF and TPF are due to the presence or absence of a die/base beneath the part, upon which it is attached, applying force in the opposite direction of the punch. The TPF process can also be divided into: Complete or Partial, which is defined be the breadth of the die under the part being contoured. Figure 4 illustrates the three processes.

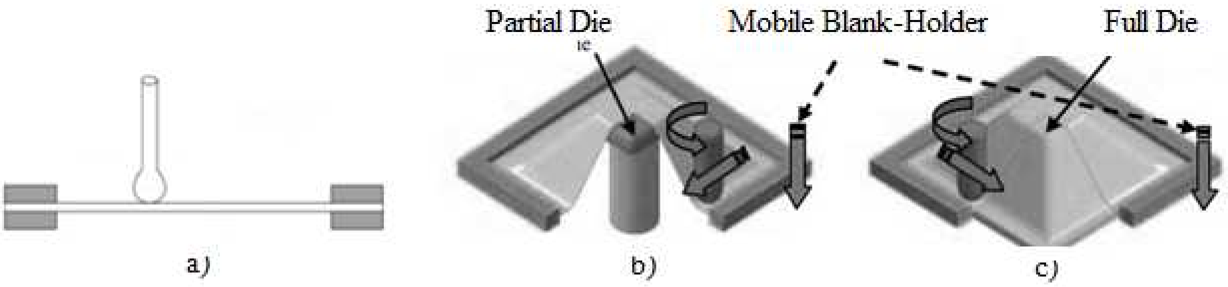

Fig. 4. Incremental sheet forming. a) SPF [13]; b) Partial TPF; c) Complete TPF [12].

For the TPF method, the sheet press should follow the punch movement in the direction of the increment, thus allowing deformations only in the region that contacts the punch.

1.3. **Computer Analysis**

In order to forecast the experimental results, reducing the elaboration and tooling application time, various factors are analyzed in the computer simulation, such as material flow, strain distribution, tool and blank optimization.

Other papers [14,18] used the computer stamping process simulation, focusing on the final geometry of the parts, achieved strain and blanks springback.

Ambrogio et al. [19] worked with the comparison of experimental and simulated results for the aluminum alloy AA 1050-0 with 1mm width. The results found between the experimental and simulated tests were very similar, confirming the potential of FEM for tools.

2. Applications

Incremental sheet forming is recommended for several industrial sectors, and can potentially be used in several production sectors. The process is recommended for various applications: (i) in medical applications, where the method allows the manufacturing of prosthetics with exclusive characteristics for each patient; (ii) in the production of small decorative objects and with architectural shapes; (iii) in rapid prototyping, in the development stages, and the creation of new products when the computer simulation is not sufficient and so the manufacturing of a prototype helps with the functional and shape analysis of the product; (iv) manufacture and repair of automobile parts; and (v) boxes for machines and electronic objects.

In Japan, using the incremental sheet forming, a prototype of the front section of a bullet train was developed (Figure 5), demonstrating that the technique can also be used for large scale prototypes [20].

Fig. 5. A model of the front section of a bullet train, made by Amino, in Japan [20].

3. Experimental Analysis

The numeric simulation was made using the LS-Dyna solver, using the LS-Prepost platform for the elaboration of the pre-process. The parameters used in the numerical simulation were the same used in the experiment, as shown in Table 1. Figure 6 illustrates the assembly of the component in the software, where the blue element is the punch, the yellow is the sheet-press, the green is the die, and the red is the sheet.

Tab. 1. Parameters used in simulation.

Parameter	Values
Increment in Z/cycle	1.25 mm
Tool Speed	400 m/min
Base Diameter	150 mm
Final Height	33 mm
Punch Diameter	8 mm
Sheet Width	0.4 mm
Yield Strength	$kf = 556\ \varphi^{0,103}$

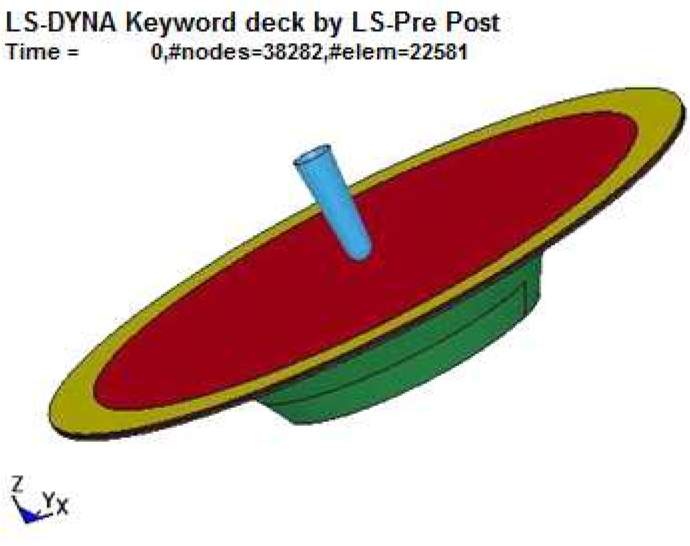

Fig. 6. Elaboration of incremental process with the software.

The experimental validation of the numerical simulation was done at SENAI CIAMATEC using the Machining Center. The method applied was the Negative process with lower support. The material used includes a metallic plate with 0.4mm width and yield strength of $kf = 556 \cdot \varphi^{0,103}$. The sheet was stamped in a cone shape with a larger diameter of 150mm and an increment angle in the "Z" direction of 30°, 45° and 60° and finished with a truncated hemispherical top. Figure 7 shows components used during experiments and Figure 8 shows the part shape after the incremental sheet process.

Fig. 7. Components used for the incremental sheet forming.

Fig. 8. Final part.

4. Results And Discussions

The characteristics evaluated in the numerical simulation were the strain paths of the three main strain, φ_1 (radial strain), φ_2 (tangential strain) and φ_3 (width strain). Figure 9 shows the final part obtained through numerical simulation with the main radial strain (φ_1) achieved, and Figure 10 shows the simulated strains path in relation to the size of the part.

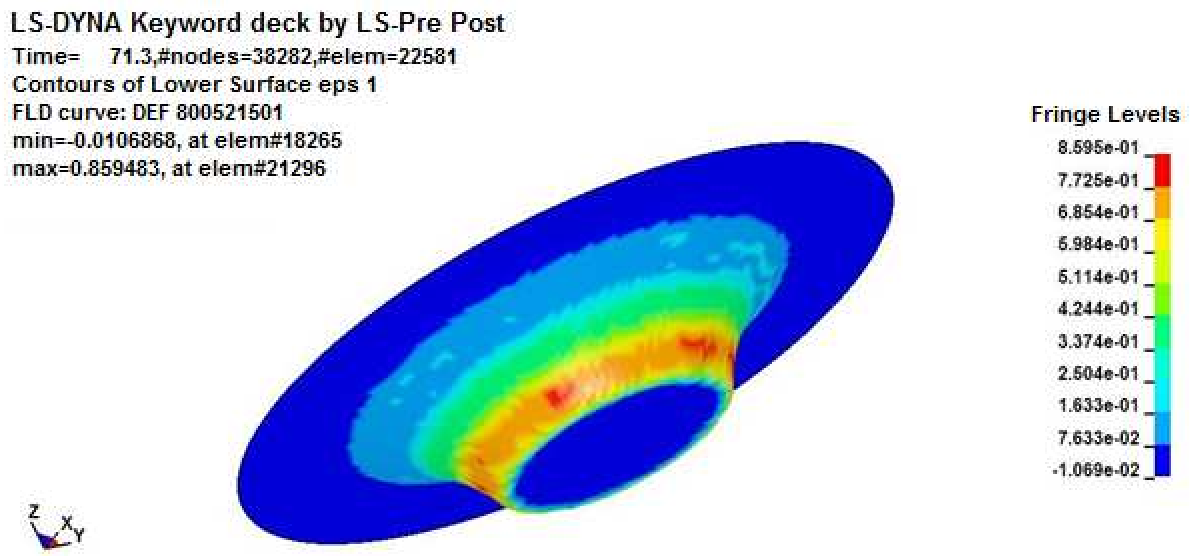

Fig. 9. Main radial strain achieved by the sheet in the simulation.

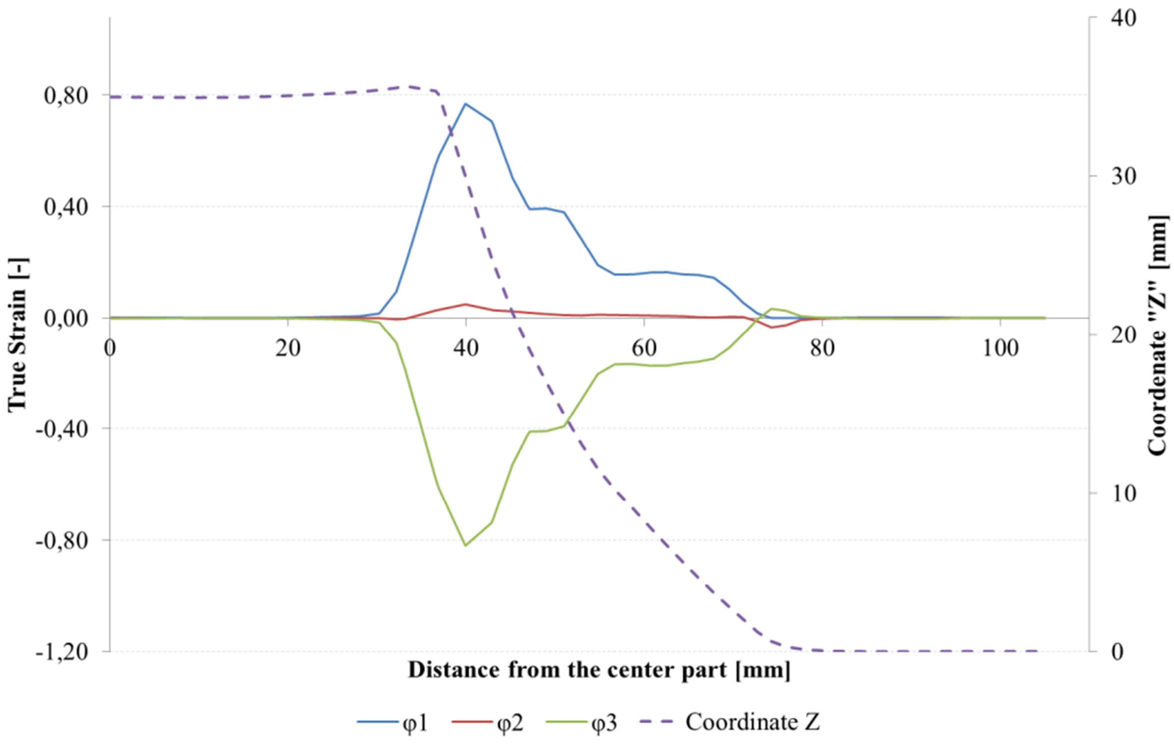

Fig. 10. Simulated strains path along the part.

Figure 11 shows the path of three main strains of the simulation compared to the real strains achieved.

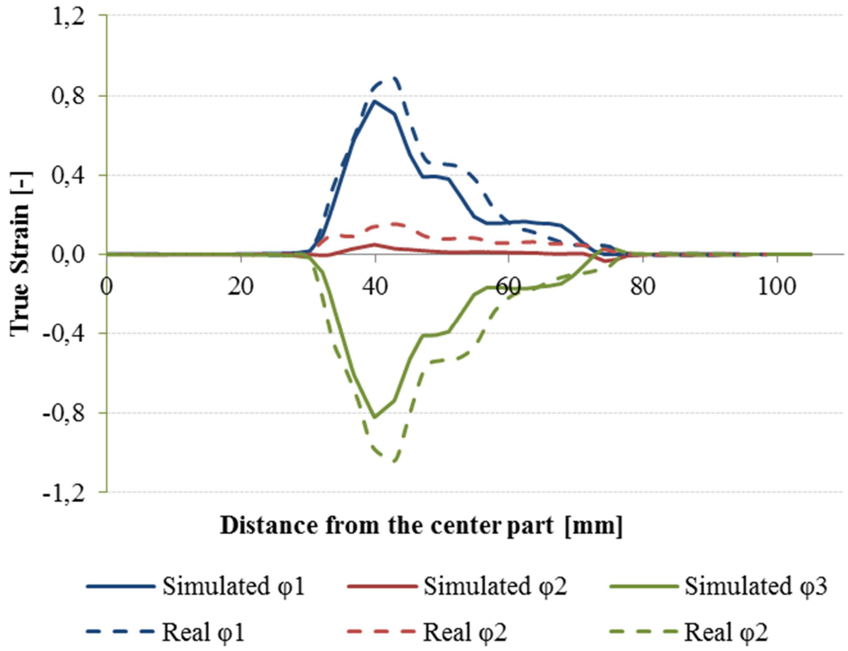

Fig. 11. Comparison between the strains paths.

Figure 12 shows the strain of the real material compared to the Forming Limit Diagram of the material elaborated by the Keller method.

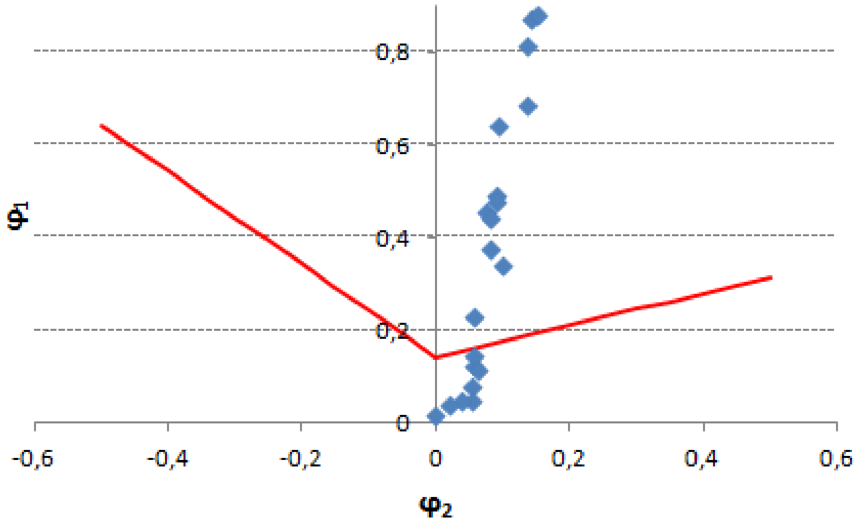

Fig. 12. Distribution of the experimental strains compared the FLD of the material.

5. Conclusion

With the incremental sheet forming, the strains imposed on the process are greater that the limits imposed by the conventional methods.

The incremental process has the characteristic of working basically with flat strains in the material, presenting values neat zero for tangential deformations (φ_2).

The numerical solution presented lower values in the analysis of the main strain paths along the part, but are greater than the limit curve for the shaping of conventional material.

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