EVALUATION OF STRESS AND STRAIN FIELD OF A THIN SHEET DURING THE INCREMENTAL SHEET FORMING PROCESS

Alysson Lucas Vieira

avieira32@yahoo.com.br

Pontifícia Universidade Católica – MG

Av. Dom José Gaspar, 500 – Coração Eucarístico – Belo Horizonte - MG – CEP 30535-901

Janes Landre Jr.

janes@pucminas.com

Pontifícia Universidade Católica – MG

Av. Dom José Gaspar, 500 – Coração Eucarístico – Belo Horizonte - MG – CEP 30535-901

Márcio Eduardo Silveira

msilveira@ufsj.edu.br

Universidade Federal de São João del Rei

Praça Frei Orlando 170, Centro, São João del Rei – MG - CEP 36307-352

Yukio Shigaki

yukio@des.cefetmg.br

Centro Federal Tecnológico - MG

Av. Amazonas 7675 - Nova Gameleira - Belo Horizonte – MG – CEP – 30510-000

Débora Francisco Lalo

debora.lalo@smarttech.com.br

Smarttech Serviços de Tecnologia

R. Jaguariúna, 882 – Holambra – SP – CEP - 13825-000

Abstract. *The industry has been looking for tools that enable the reduction of costs in the product creation stages. In the sheet metal forming industry, the stamping is a process widely used for large scale production, however a high investment in heavy punches and dies is required. Being a relatively old process within the engineering, the study of its forming is well established. Recently, in order to reduce the use of dies and punches, it has been developed a sheet forming method known as Incremental Forming. It is a slow process compared to conventional method. Currently, its usage is focused on the production of small scales and prototypes. This work presents a study of the stress and strain fields of a steel thin sheet during the process of Incremental Forming, using the Finite Elements Method. The results showed that, unlike conventional stamping, the plane stress state does not prevail during the plastic forming process, which suggests new elements for a better correlation.*

Keywords: *Stress, Strain, FEM, ISF.*

1 INTRODUCTION

According to Jackson and Allwood (2008), incremental forming is a flexible process, which the metal is shaped by a progressive located strain. It is flexible because it does not need special tools and a simple tool can move along of the entire surface of the component to be shaped in a certain way, which produce a highly localized plastic strain.

In this process, it is usual use machines, such as milling machines, CNCs, robots or other special servo-controlled machine, which the tool is built on the vertical axis of the machine (CAVALER, 2010). It is a slow process, which it is possible produce from 1 to 500 parts per month (PAUNOIU et al 2006).

Leszak created the idea of incremental forming in 1967; however, there was not enough technology to make the idea feasible at this time. It was only possible because of the creation of the computerized numerical control machines, the CNC's (SENA et al., 2011). The Figure 01 shows the machine created by Leszak.

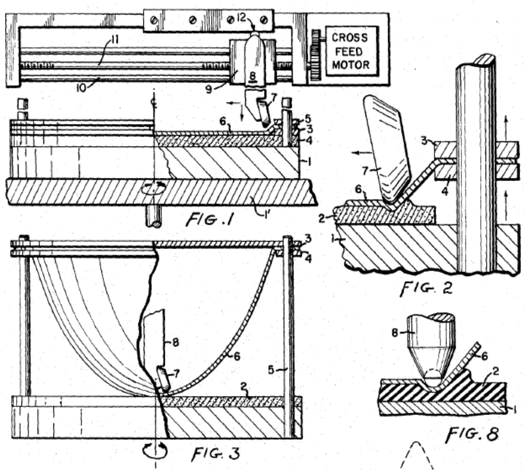

Figure 01: The machine created by Leszak

According to Kopac and Kampus (2005), the industry has a demand for more complex products. However, it has a disadvantage cost because for each component it is necessary to make a tool for forming it. Therefore, this type of forming is advantageous only for a great number of components.

Currently, the process of incremental forming is gaining more space, because it is a viable economic method. In addition, it does not require a toll made of an extremely durable material and a high number of moving parts. If it were necessary, the requirements for a manufacturing process would have higher value added (TUOMI et al., 2004, quoted in SILVA et al., 2011).

In fact, the basic concept is to avoid the traditional matrices, giving the puncture the function of progressively shape the final form of the component designed. This design significantly reduces the equipment cost, even when the slowness of the process reduces its advantages in terms of cost, for example in case of hundreds of identical products should be produced (BERTOL et al., 2012).

The incremental forming is a low-cost sheet metal forming process. Because of that its applications is increasing in fast prototyping, biomechanics and production of small batches of sheet metal components (MARABUTO et al., 2011). Other reason of this increase it is the fact that the conventional forming has a costly process of try out for the production of small batches of components (SILVA, 2011).

The incremental forming process can be divided according to the number of points and tools used, such as single point or double point, with negative or positive tool (ALLWOOD et al., 2005). The Figure 02 shows some types of the incremental forming process.

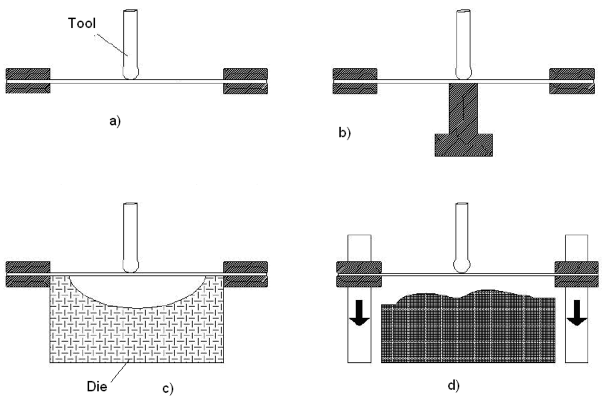

Figure 02: A) single point forming, b) double point forming, c) using negative matrix, d) using positive matrix

2 SINGLE POINT INCREMENTAL FORMING (SPIF)

The simple point has been earning more changes of development among the incremental forming types, because it does not need a specific tool to become each product shaped (PETEK et al., 2009).

This type of forming only works using a punctual tool, which shapes the blank, which is attached at its ends, which are fixed. Because of that, there is no motion of the blank caused by its attachment as occur in the double point process. The Figure 03 shows a draf of the SPIF process.

.

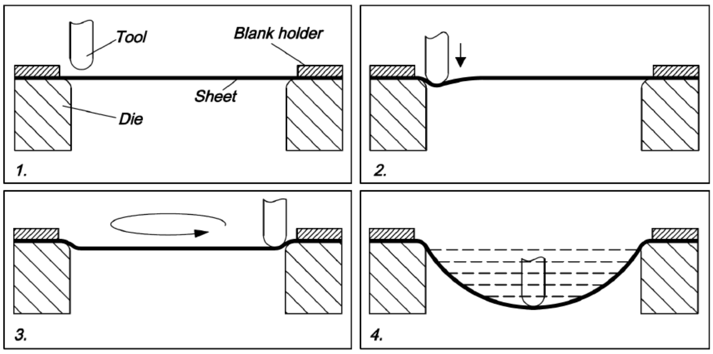

Figure 03: SPIF

The same CNC can be used for making different parts with different geometry. However, according to the size of the component and the modification of the support bracket of the blank, the CNC may need to be exchanged.

Within this process may still have a variation of positive and negative forming (SILVA, 2011), as shown in the Figure 04.

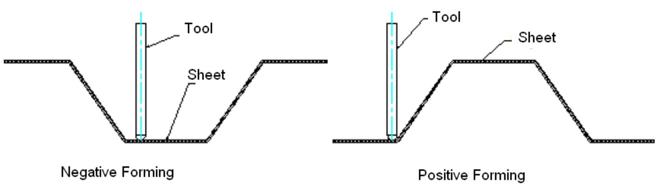

Figure 04: Negative and Positive Forming SPIF

The definition of positive and negative is given by the concavity part shaped, which can be concave up or concave down.

In the case of the mechanics of the incremental forming process using the single point, Rodrigues advises that the ratio between the tool diameter and the thickness of the sheet is very high. Therefore, it is possible assuming that the adjacent material to the tool is undergoing a process of plane strain state (RODRIGUES, 2005), as shown in the Figure 05.

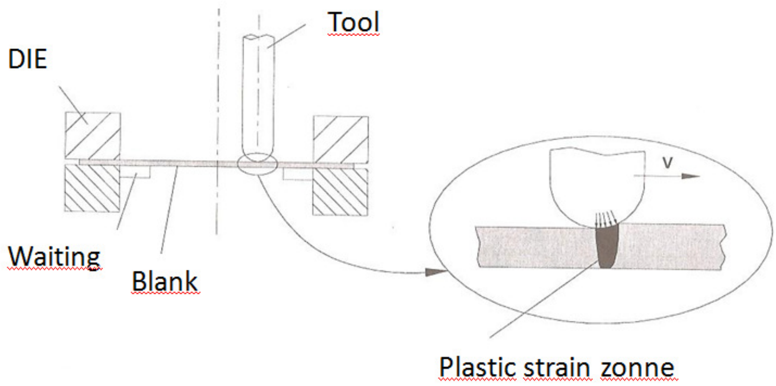

Figure 05: Material on the plane state of strain (RODRIGUES, 2005).

Thus, the strain field can be given by the following expressions (RODRIGUES, 2005):

$$\varepsilon_2 = 0 \qquad \varepsilon_1 = -\varepsilon_3 = \frac{\gamma}{2} \qquad \bar{\varepsilon} = \frac{2}{\sqrt{3}}\varepsilon_1 = \frac{1}{\sqrt{3}}\gamma = \frac{\cot g\alpha}{\sqrt{3}} = \frac{\tan\phi}{\sqrt{3}} \tag{1}$$

The $\bar{\varepsilon}$ is the effective strain found during the process.

The academic research about incremental forming began in the early 90s in Japan, and more recently, the interest about it increased between Europeans and Canadians (JACKSON et al., 2008).

Currently, the studies about incremental forming are focused on the experimental and numerical fields (MARABUTO et al., 2011) and for the numeric part; the tool used is the finite element.

The finite element numerical simulation (FEM), has been widely used in various industrial segments, with this method can be anticipate the physical tests results and also study details of models that can hardly be studied in physical parts, or lack of technology or high costs related to instrumentation.

The use of numerical simulation tools, especially those using the finite element method, has wide acceptance in the field of mechanical engineering. With the evolution of computers with increasingly powerful processors, enables the simulation with greater detail, using more complex models and boundary conditions with the largest representation with reality.

The present study aims to understand through numerical simulation what occurs in the field of strain and stress along the thickness of a part forming to the incremental stamping process by single point. A numerical finite element model with 3D elements, was used to elucidate the theoretical basis and this numerical model was correlated with a physical model.

3 METHODOLOGY

In order to obtain the results in numerical model, it has been correlated with a physical component, formed by the single point incremental process.

The Figure 06 shows the CAD of a truncated cone that has been physically manufactured and performed by finite elements.

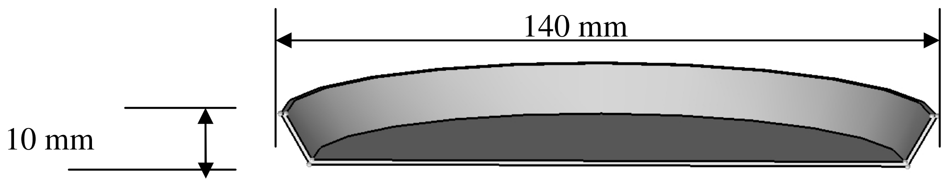

Figure 06: Truncated Cone Measurements

For the construction of the trunk by incremental forming, the physical component, it was used a CNC machine (ROMI manufacturer, line Discovery 560), which is available in the laboratory of PUC-Minas, as shown in Figure 07.

Figure 07: CNC machine used for the incremental forming process

The Figure 08 shows how the assembly of the components for the forming of the truncated cone occurred.

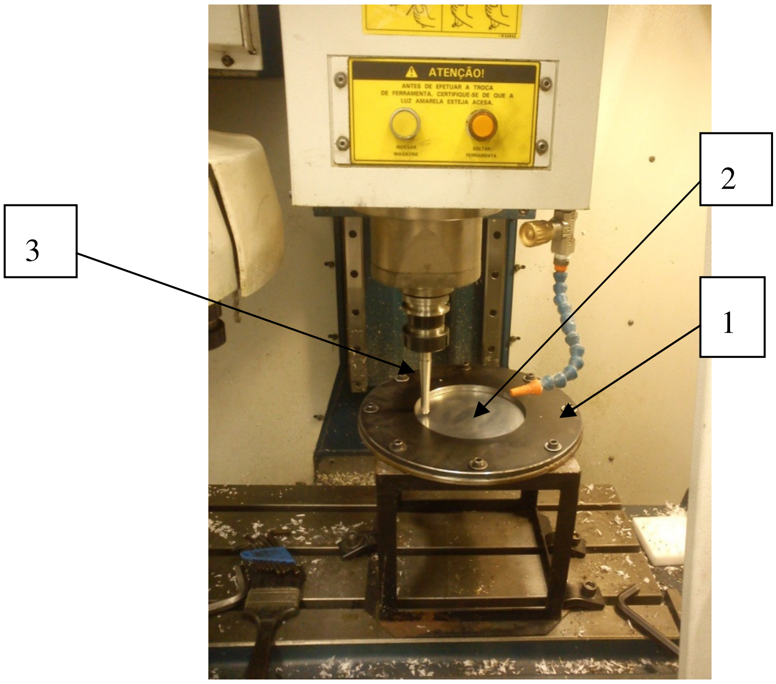

Figure 08: Assembly of the components for the forming process

Thus, the Figure 08 has:

- 1 blank bracket fixing - Die
- 2 Blank to be forming in SPIF
- 3 Forming tool in SPIF

For the correlation with the virtual model, the strains in the plane of the blank, ε_1 and ε_2, were measured by components drawn with a square mesh before forming the component by SPIF. This way, it is possible to perform the measurement of the strains in the sheet plane after forming. The Figure 09 shows the strained component.

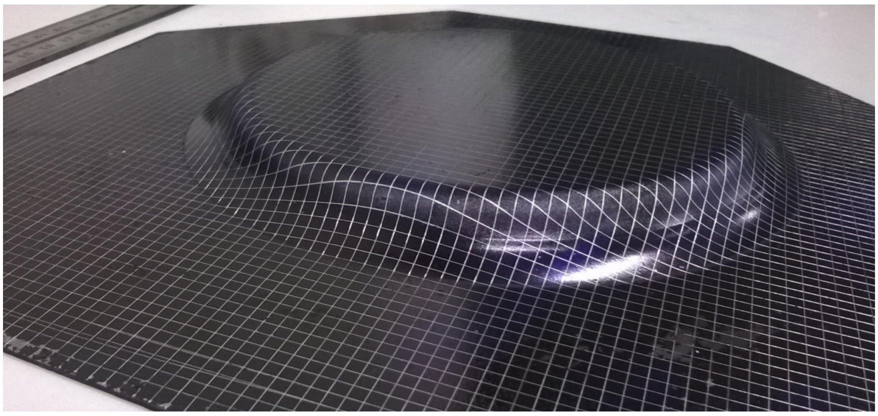

Figure 09: Strained mesh for the measurement of the strains ε_1 e ε_2

The numerical finite element analysis was made implicitly considering nonlinear material of contact and geometry. The software used for the analyzes are the HyperMesh 11.0 as the pre-processor, the Abaqus 6.10 as the processor and the HyperView 11.0 as the post processor.

The FEM model and the elements used throughout its thickness can be seen in the Figure 10.

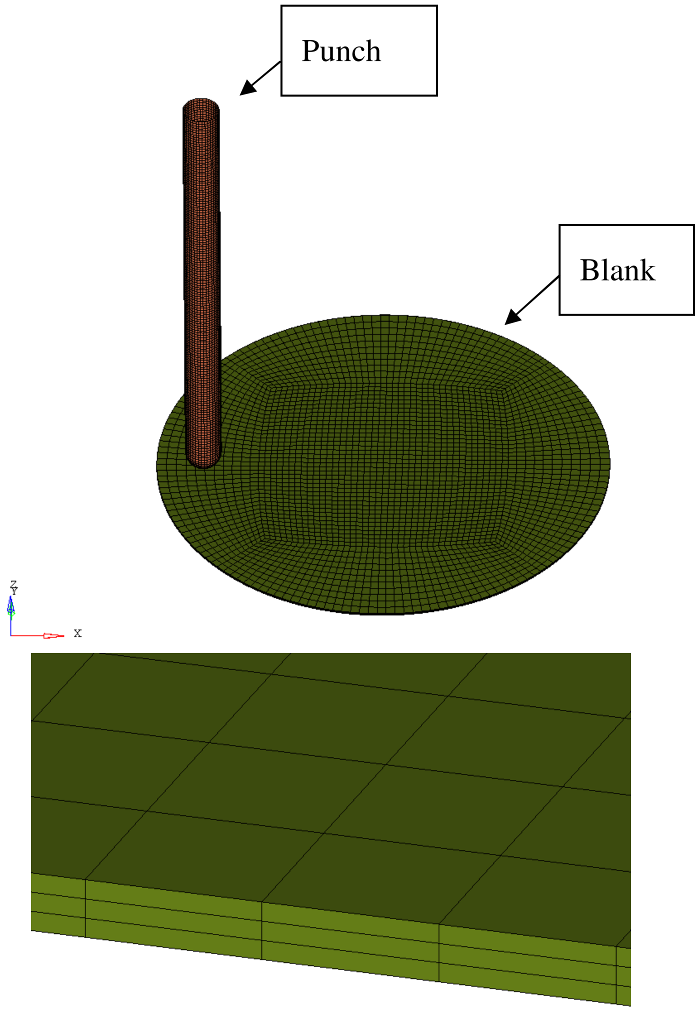

Figure 10: Model of the Incremental Forming Process – Detailed used Elements

The model has a punch, which will incrementally forming the blank. The model of the blank is constituted by 3D components, hexahedral, and the model is restricted in its entire tip. After obtain the results, it was performed the comparison between the numerical and physical models.

4 RESULTS

In order to validate the virtual model after the incremental forming process, it was used a comparative of the strains which was found at the end of this forming process. The measurements of ε_1 and ε_2, which are the strains in the sheet plane, were performed.

The Figure 11 shows the measurement region, where the first one is regard to the virtual model and the second one for the physical model. The Y direction were considered in the axis which the tool contacts the blank for the first time. In addition, the measurement was carried from the edge to the center, which is the beginning of the bend of the virtual model and the beginning of the bend to the center in the physical component.

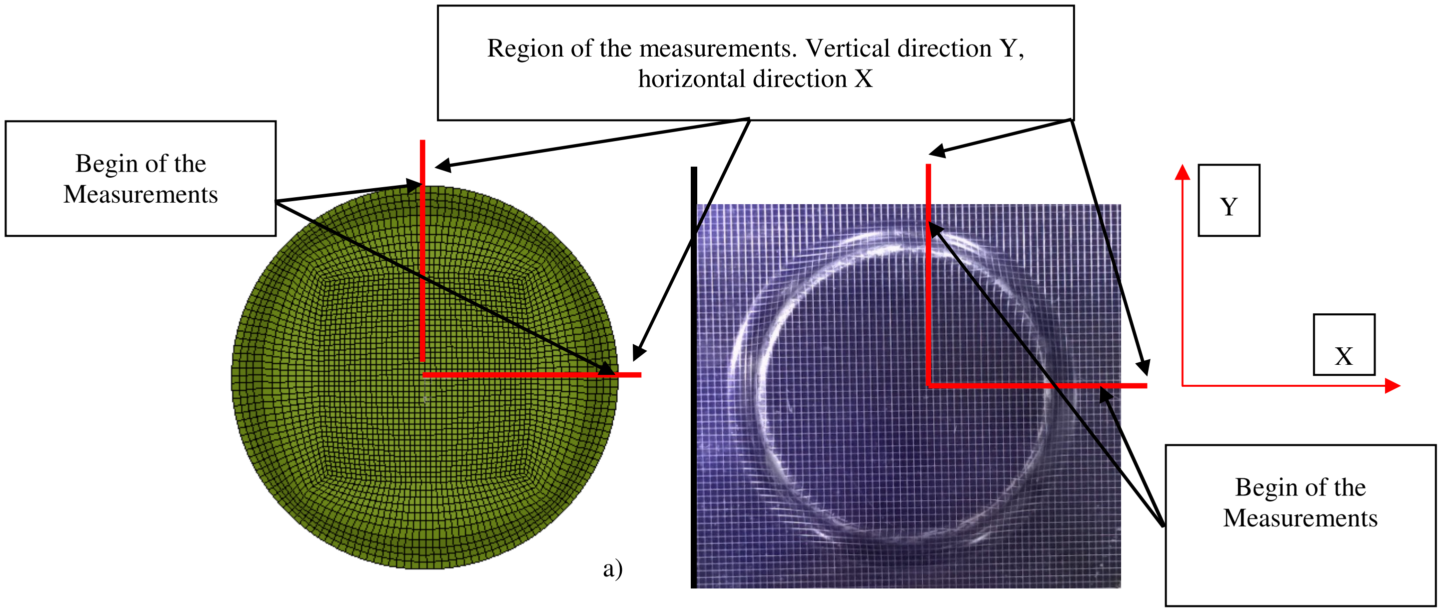

Figure 11: Draft of the measurements of the strains in the plane. a) Virtual Model; b) Physical Component

The measurements were performed on two samples of physical components, which were shaped on the CNC by incremental forming. They are described in the following graphs as Physical 1 and Physical 2 and the results were compared with the numerical model. The Figures 12 and 13 show graphs of the comparison between the strains on the plane directions.

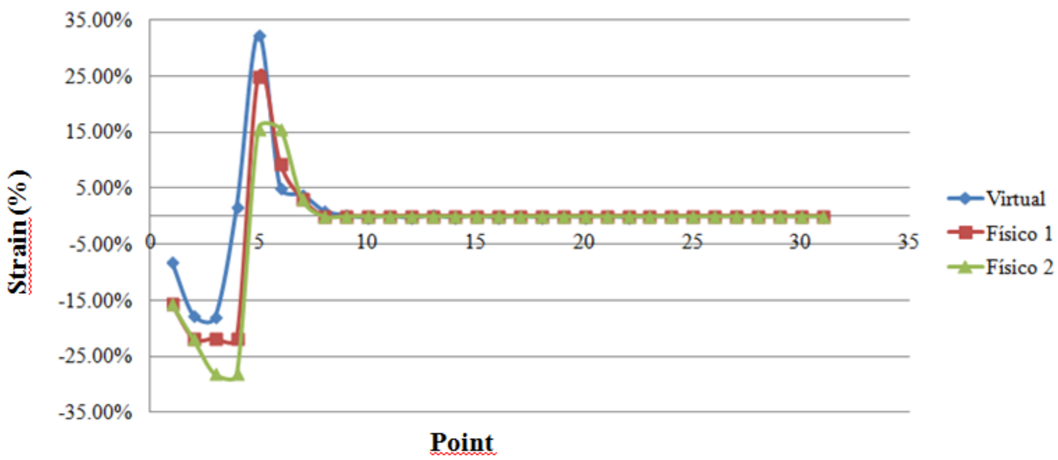

Figure 12: Comparison of the strains on the X direction

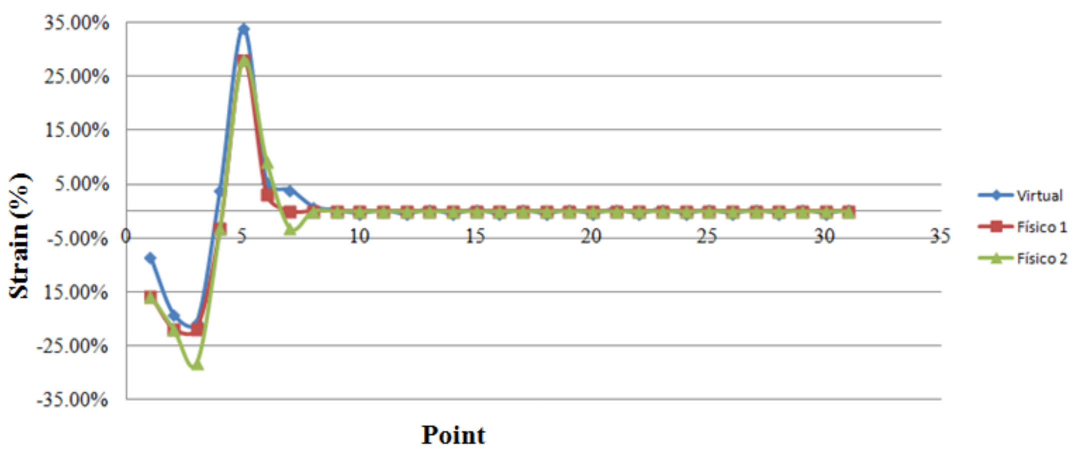

Figure 13: Comparison of the strains on the Y direction

Based on the graphs, there is a similar behavior in all comparisons.

4.1 Results of stress and strain on the FEM model

For checking what occurs in the stress and strains of the blank during the forming process by SPIF, a point called A was chosen to be monitored during the entire analysis. This point was further divided into four other points as shown in Figure 15, which were choose along its thickness. The Figure 14 shows the position of the point A according to the other points presented.

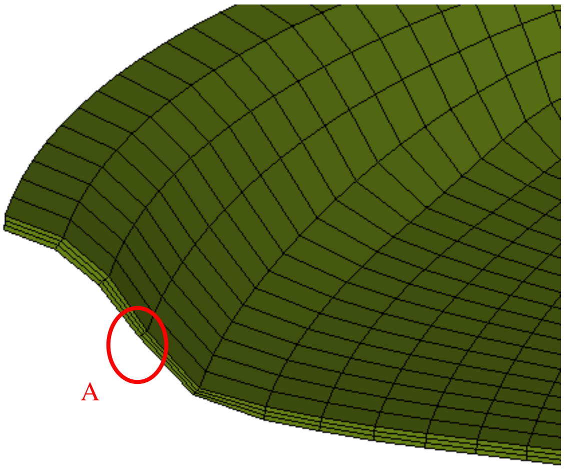

Figure 14: Point A, stress and strain monitoring along the conforming process.

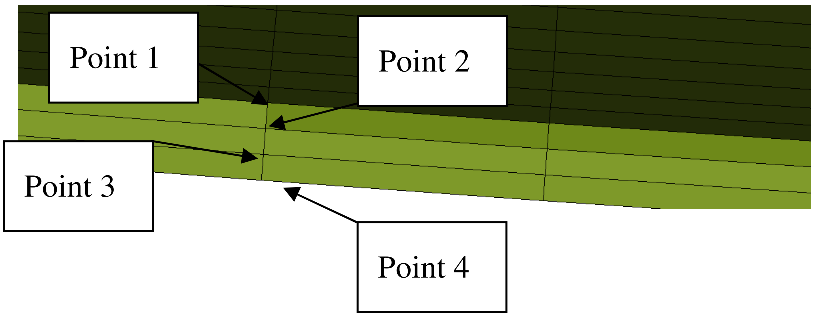

Figure 15: Points along the thickness

The stress and strain graphics were performed according to the chosen point monitoring the values and the behavior. It occurs with these stresses and strains at this point during the entire forming process. In other words, independent of the puncture position during the forming process, the studied point is always the same. The Figure 16 shows the graph for the stress σ_{XX}, along the thickness at the point A

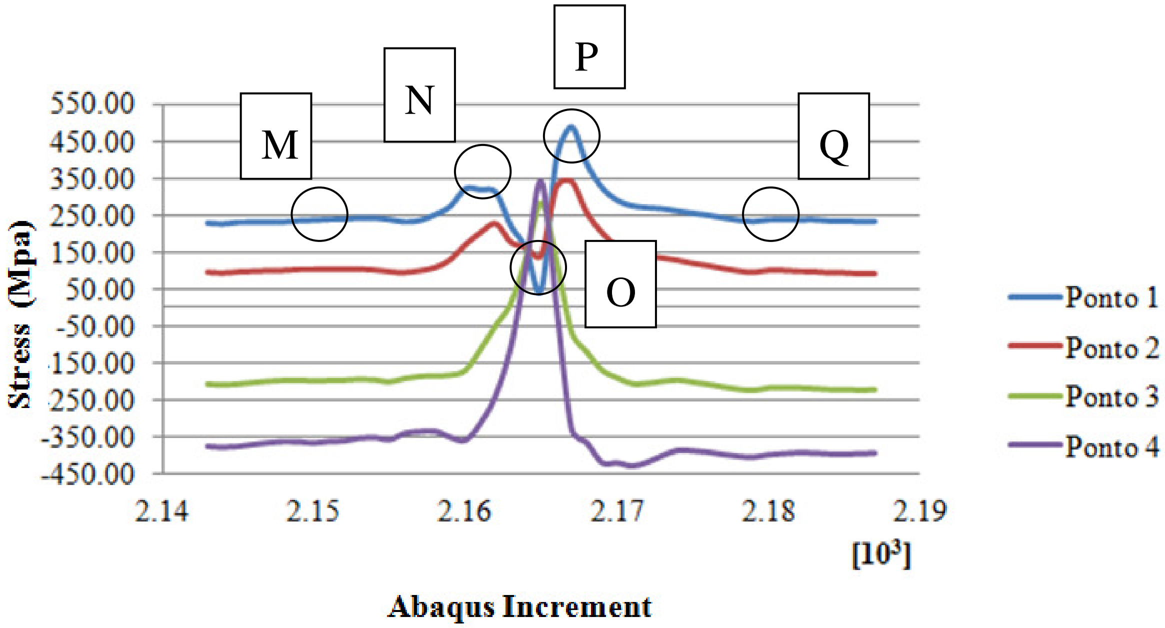

Figure 16: Stress σ_{XX}.

It was observed in these moments that when the punch passes over the point A in evidence (instant O), there is a decrease in the stress at the top (point 1) and in the region just below the same point (point 2). In addition, in the lower layers (points 3 and 4) the stresses pass from compression to traction, getting larger values than the values of the stresses of the upper layers.

After this moment (time P), the points 1 and 2 increase the stress values and the points 3 and 4 return to the previous level of compressive stress.

Finally, in the last time point (Q) the stresses remain stable until the next cycle, which happen in the same way, but with different stress values.

For the same instants, the Figures 17 and 18 show the stresses at σ_{YY} and σ_{ZZ} directions.

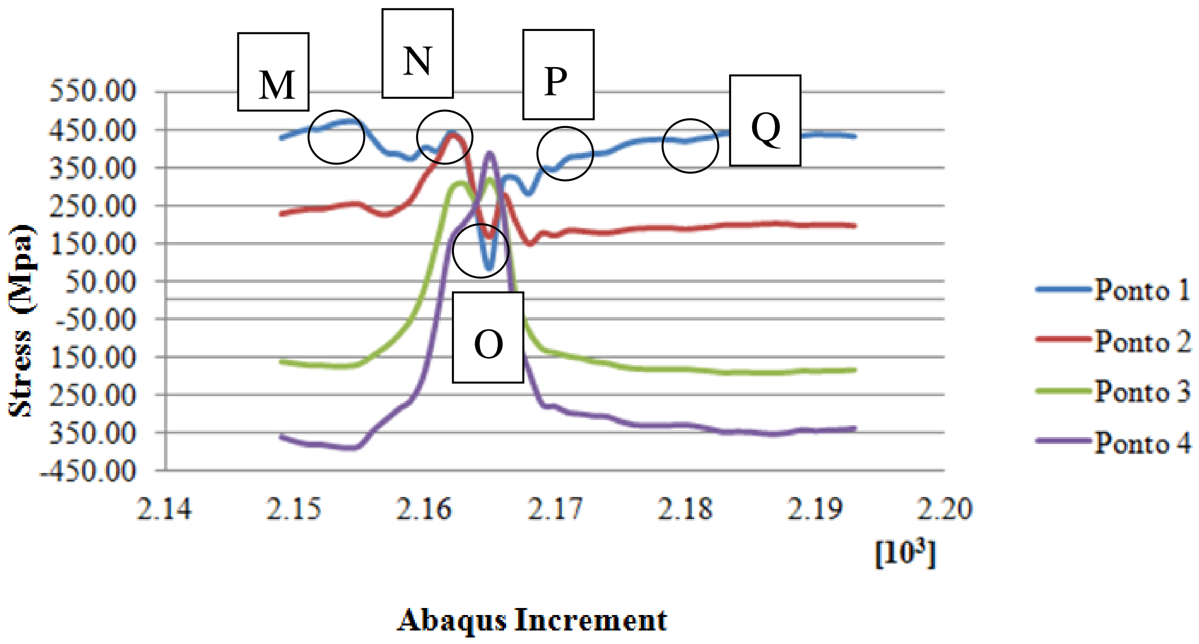

Figure 17: Stress σ_{YY}.

In addition, to this stress value, it is possible observe a decrease of the stress at the points 1 and 2 and an increase at the points 3 and 4. Moreover, at these points (3 and 4) occur a change from compression to traction exceeding the stress values at the points 1 and 2 during the instant which the puncture pass through the studied point as occurred for the σ_{XX} stress graphs.

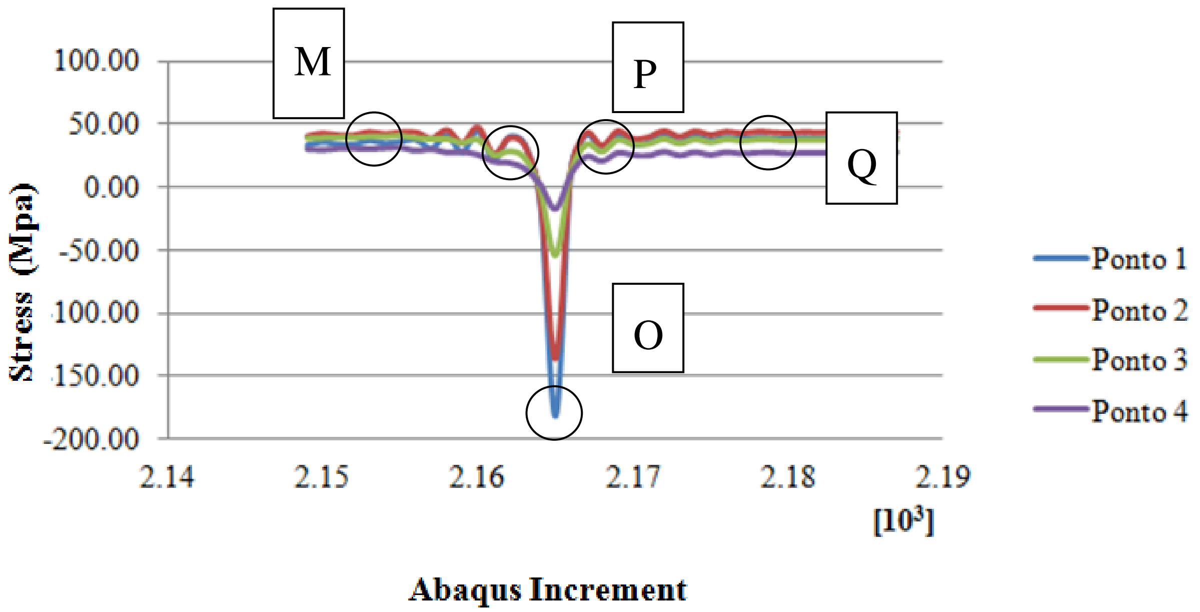

Figure 18: Stress σ_{ZZ}.

For the behavior of σ_{ZZ} stresses, it was observed that they behave similarly. All stress are traction stresses before the puncture form the point A. The puncture comes into contact with this point causing the biggest compression stress across the entire thickness with a non-homogeneous stress variation and a greater variation at the point 1 and a less variation at the point 4. Therefore, the upper region of the blank, which comes into contact with the puncture, is most requested regards this stress.

Regards the behavior of deformation, the same studied instants for helical trajectory are showed in the Figures 19 to 21.

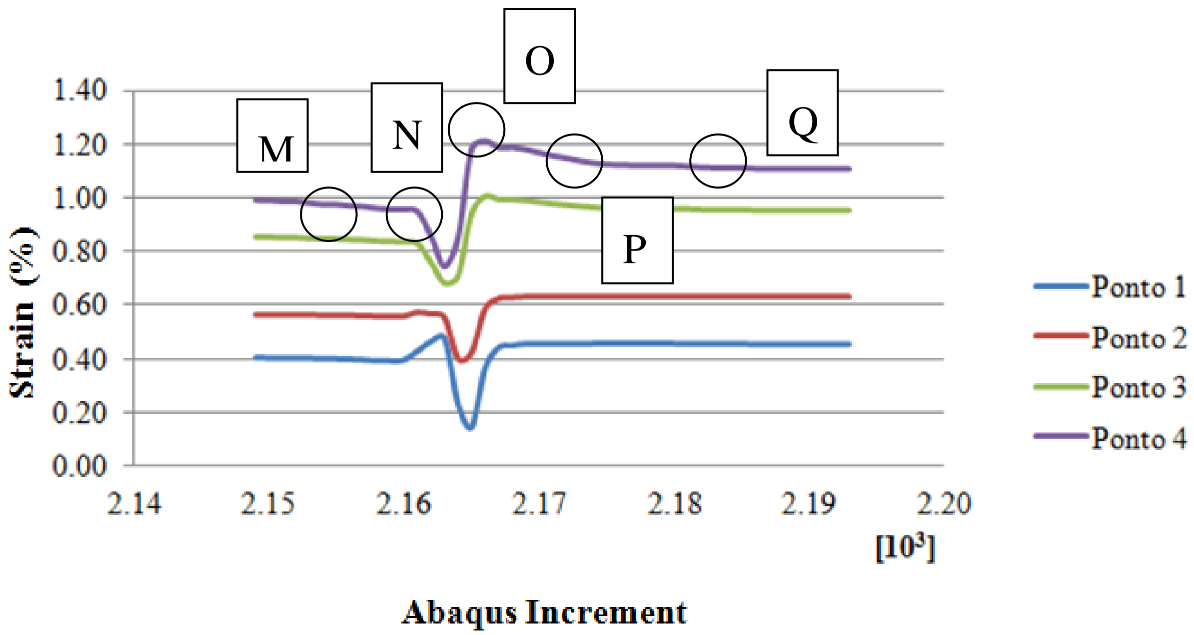

Figure 19: Strain ε_{XX}

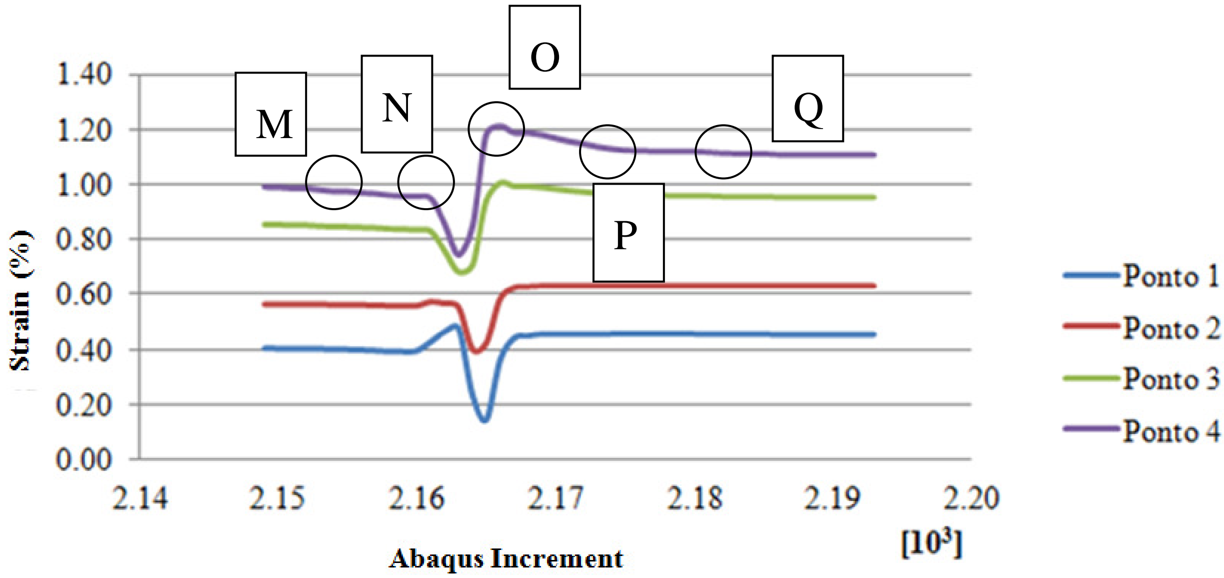

Figure 20: Strain ε_{YY}

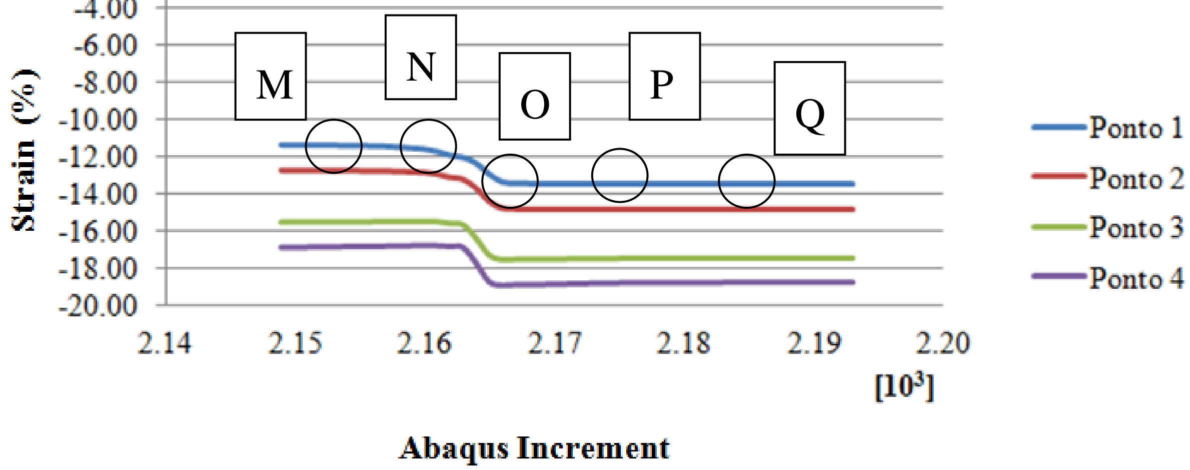

Figure 21: Strain ε_{ZZ}

The Strain graphs show the same behavior, which the strains begin in an initial level and the point suffers a conforming by the puncture (instant O), passing the strains to a new level.

In relation to the strain values, the higher points (1 and 2) show a similar variation strain of the lower points (3 and 4), which suggests a plane state of strain during the conforming process.

5 CONCLUSION

The goal of this study was to evaluate the behavior of the stress state and strains in a component which suffers incremental forming by stamping, using a numerical model in order to have better understanding of the mechanics of this type of process.

The stresses during the forming process have a pattern behavior in σ_{xx} and σ_{yy} .The values in the upper part come into a traction constant and the bottom come in compression. However, in the instant that the forming tool passes at the point to be strained, the bottom begins to undergo traction and the upper portion has its stress values reduced. There is an increase of the stresses at the instant immediately after the forming process. The values of the stresses are higher than they were before the conforming process and then, they return to their previous values. This variation suggests that a traction of the material is caused by the puncture at the top region. The σ_{zz} stresses have a constant value of traction. However, at the time of the forming process, a reduction of this number occur in both upper and lower parts, suggesting compression and subsequent return to the previous stress values after the forming process. However, there is a relative variation of the values of the different points; therefore, it is possible to discard a plane stress state, which occurs in conventional stamping. This cycle repeats during the entire forming process, varying only the values of the stresses, which reach a maximum peak and then decrease at the same time, which the forming tool becomes far from a shaped point.

The strains have a more defined behavior, which ε_{xx} and ε_{yy} are strains of traction and compression and ε_{zz} is a compression strain. However, both comes from a constant values level. After the forming process, they homogeneously increase their values, both in the lower and in the upper part of the blank. This occurs at the instant which the tool forms the point.

By observing the instant of the forming process, it is noticeable that the ε_{zz}, strain presents a relative variation of similar values at the studied points along the thickness, suggesting a plane strain state at the instant, which the point is formed by the puncture.

ACKNOWLEDGEMENTS

We would like to thank FAPEMIG for the assistance provided.

REFERENCES

ABAQUS/Standard *User Manual*, Version 6.10, 2011.

ALLWOOD, J., BRAMLEY A., RIDGMAN, T. e MILEHAM, A. *A Novel Method for the Rapid Production of Inexpensive Dies and Moulds with Surfaces Made by Incremental Sheet Forming*, Proc. IMechE Part B: J. Engineering Manufacture, 220, No. 2, p. 323 – 327. 2005.

BERTOL, L.,S., FOLLE, L., SCHAEFFER, L. e KINDLEIN Junior, W. *Avaliação dos ângulos-limite na estampagem incremental de alumínio e titânio*. In. Corte & Conformação de Metais, Brazil. 2012.

CAVALER, L. *Parâmetros de Conformação para a Estampagem Incremental de Chapas de Aço Inoxidável*. Tese Doutorado, UFRS, Porto Alegre. 2010.

JACKSON, K. e ALLWOOD, J., *The Mechanics of Incremental Sheet Forming*, Journal of Materials Processing Technology 209, 2009, 1158 – 1174 - 2008

KOPAC, J. e KAMPUS, Z. *Incremental Sheet Metal Forming on CNC Milling Machine Tool*. 13º International Scientific Conference on Achievements in Mechanical and Materials Engineering. Gliwice, Polônia. 2005.

LESZAK, E. *Apparatus and Process for Incremental Dieless Forming*. In. US Patent US3342051A1. 1967.

MARABUTO, S., SENA, J., AFONSO, D., MARTINS, M., et. al. *Estampagem Incremental: Estudo Numérico e Experimental*. In. Congresso Métodos Numéricos em engenharia,Coimbra, Portugal. 2011.

PAUNOIU, V., EPUREANU, A., NICOARA, D. e CIOCAN, O. *A Review of the Sheet Metal Forming Methods Using Reconfigurables Dies*, Dunarea de Jos, V. 1, p. 1221-4566. 2006.

PETEK, A., KUZMAN, K. e KOPAC, J. *Deformations and forces analysis of single point incremental sheet metal forming*. In. Archieves of materials science and engineering, Vol. 35, p. 107-116. 2009.

RODRIGUES, J. e MARTINS, P. *Tecnologia Mecânica – Tecnologia da Deformação Plástica – Vol. II Aplicações Industriais*. Escolar Editora, p. 421, 610 - 619. Lisboa. 2005.

SENA, J., VALENTE, R. e GRÁCIO, J. *Finite Element Analysis of Incrementally Formed Parts*. Int. J. Mechatronics and Manufacturing Systems, Vol. 4, No. 5. 2011.

SILVA, P. Estampagem Incremental Utilizada para Prototipagem de Peças de Aço ABNT 1008 e ABNT 304. Dissertação de Mestrado, Universidade de Brasília. 2011.

TUOMI, J. e LAMMINNEM, L. *Incremental Sheet Forming as a Method for Sheet Metal Component Prototyping and Manufactoring*. Assises Européennes de Prototypage Rapide. Sep. 14 e 15. 2004.