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NUMERICAL STUDY OF DUAL PHASES STEEL ON INCREMENTAL SHEET FORMING

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Abstract. *Advanced High Strength Steel (AHSS) such as Dual Phases, TRIP and TWIP, are increasingly common in the automotive industry, due to its excellent strength and good formability after mechanical forming. Dual Phase steels (DP) consist of a matrix of ferrite containing a second phase of martensite in the shape of islands. The high hardening rate coupled with excellent stretching confer to DP steel, a final stress higher than that of conventional steels of similar yield stress when subjected to a plastic forming process. A recent forming process, known as Incremental Sheet Forming (ISF), has produced encouraging results. It is based on the use of a spherical tool that deforms punctually a plate through a predetermined path. This process, which can be done on a CNC machining center (eliminating the expensive presses and dies of conventional process), reaches levels of strain above those achieved by traditional sheet forming, making it ideal for the manufacture of parts with complex geometry. However, depending on the inclination of the deformed surface, the thickness reduction can be quite high, exceeding 50%, resulting in a structure with a thickness highly thinner than the original blank. In the literature one can find several papers relating the use of incremental forming with aluminum alloys and conventional steels. The purpose of this work was to evaluate, by numerical simulation, the use of incremental forming on two types of steels with same strength class, but with different hardening rates: a DP and a HLSA. Preliminary results have showed that despite the loss of stiffness caused by reduction of thickness during the incremental forming process, the high hardening rate of DP can provide structural benefits to the final component.*

Keywords: *Incremental Sheet Forming; Dual Phases; Numerical Simulation*

1. INTRODUCTION

Throughout the ages, due to demand from the automotive sector, metallurgical industries comes developing new steels for the greater strength and lightness, which can be an improvement in the design of automobiles. In an industrial setting, the transformation process metalworking is highlighted, where increasingly is worked with a rational use of resources, therefore avoiding unnecessary expenses and always looking for materials with high strength and lighter. In this new industrial scenario steels Dual Phases and HSLA steels stands out by having high durability and less weight compared to conventional steels.

The new generation of steel multi-phases (such as HSLA, DP, TRIP and TWIP) aims to achieve the goals of high performance and lightness. These new steels can reach very high levels of resistance, with moderate ductility, which make them ideal to absorb energy during an impact automotive. Theirs high strength, allows fabricate structural components thinner than those made with conventional steels, making the vehicle lighter.

Steels of medium and high strength are micro alloyed steels that show good values of strength associated with adequate ductility. These characteristics are obtained by adding alloying elements such as titanium and niobium, which together, with a thermodynamically controlled process, promote hardening of the steel structure due to the formation of thin precipitates and the refinement of ferrite. High mechanical strength allows the substitution of less resistant materials with reduced thickness and/or strength gain of parts.

Between the high strength steels, there are the HSLA on which the linkers elements provides better mechanical properties, or better corrosion resistance compared with the carbon steels. Also they have a good forming and welding properties. The positives in relation of rendiments are that they strengths of income may vary their yield stresses between 250-590 MPa. Due to their higher strength and toughness HSLA steel typically require 25-30% more energy to form, compared to carbon steels. They are widely used in cars, trucks, bridges and many other structures in which are designed to handle large amounts of stress, and need to get a good strength-to-weight ratio, but these steels have a limited formability despite offering good mechanical strength.

Dual Phases steels possess a high mechanical strength with good ductility; this fact is active by the existence of grains of martensite in the ferrite matrix in its structure. When these steels suffer initial deformations, those focus on the weakest material. But the contour of the ferrite grains contain martensite islands (high strength), which resist the strains of the ferrite phase, thereby generating a high work hardening rate characteristic of these steels. This high work hardening rate added to the significant stretching DP steels give a strength voltage greater than the conventional steels

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with the same yield stress. Depending on its composition, the DP steels with 0.2% strain, can reach up to 80% of its tensile strength.

Among the developments that have occurred in the automotive industry emerge the incremental sheet forming, on which a simple geometry tool performs the conformation of a metal plate through successive deformations contours applied locally (Park and Kin, 2003).

The ISF is a process which is performed gradually by the action of the punch that passes crossing a predetermined path programmed for a required geometry. The blank to be chosen need to has appropriate mechanical properties, due to large requestor's efforts, and plastic deformation during the whole process. During the process, the original sheet which is fixed has a reduced thickness at the location where deformation occurs.

According Jeswiet (2001), this process is used for conformation a sheet metal into complex shapes without the use of arrays, using a metal tool contact point, mounted on a machining center, in order to deform it through moving the piece and/or tool, particularly in the vertical plane. In ISF, the tool produces a plastic deformation, located in a small region of the plate, this region changes according to the movement of the tool over the plate. Thus, the deformation occurs in a progressive way, allowing a high degree of conformation, compared with the conventional stamping processes (Martins et al. 2008).

In the process of ISF, there is advantages as the possibility of deforming parts either asymmetric or symmetric, and these parts can be obtained directly from an interface CAD / CAM using a conventional machining center (CNC), thereby making the process even more favorable because it enables the reduction of time/cost of production and is feasible to applications for small lots or scale unit.

The numerical simulation software have become a necessary tool for obtaining results of stresses and displacements of structural components, it is noted that this avoid unnecessary expenses through trial and error, or through the construction of prototypes for possible testing.

This work aims to analyze and compare the incremental stamping (ISF) in two types of steels, a high-strength Dual Phase (DP450) and one HSLA, by numerical simulation, all this was done using the commercial finite element software (RADIOSS), which owns explicit simulations robust enough to handle all the non-linearity of the model.

2. METHODOLOGY

For this work, were simulated by finite element method two stamping process by ISF, with two different materials: Dual Phases (DP450) and steel HSLA. Then a comparison was made to analyze the stresses that appeared during the process and thickness reduction of the stamped plate.

2.1 Materials

The materials used were the ones cited above, DP450 and HSLA, whose conventional stress x strain curves are given in the Figure 1. The elastic properties are showed in Table 1, where was considerate that the elastic part of the curve the both materials have the same properties.

Table 1 – Elastic properties of the materials

E (MPa)	ν	ρ (Kg/m³)
210000	0,30	7850

Despite both materials possess good mechanical resistance, the DP steel differs for its high work hardening rate, despite having a yield stress somewhat lower in comparison with HSLA, during the stamping process, the high hardening rate that the steel DP get tensions very much higher than HSLA in plastic regime, this behavior can be noted in the graphic bellow.

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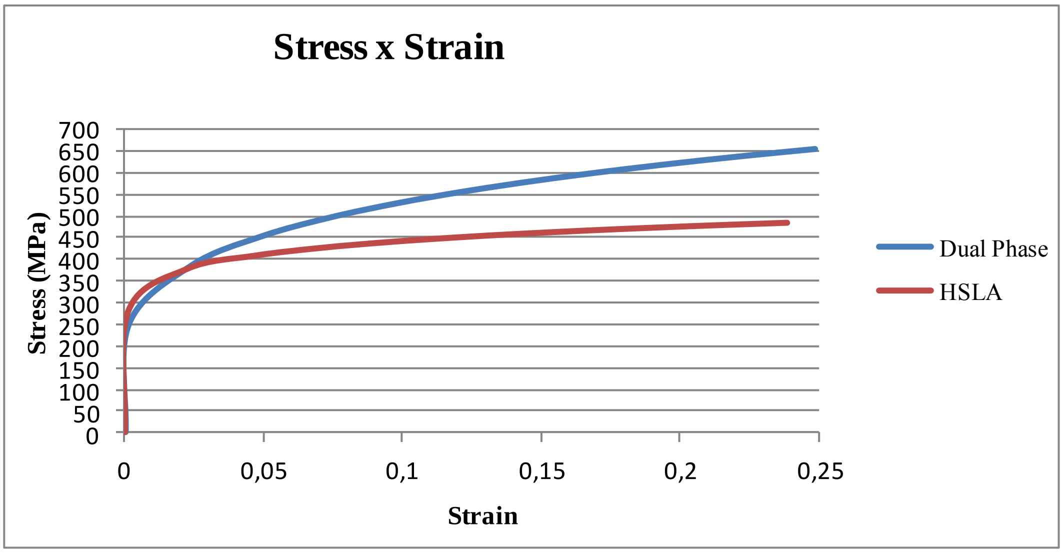

Figure 1-Grafic Stress x Strain

2.2 Incremental Sheet Forming (ISF)

Incremental Sheet Forming is an emerging process to manufacture parts that are well suitable for small batch production and/or for complex geometry. Mounted in CNC machine, this method aims to deform punctually and plastic a sheet metal blank by its movement and/or by the stamping tool, especially in the vertical plane (Jeswiet, 2001).

In this work the metallic tool used to stamp was modeled as a rigid sphere with 12mm of diameter, which descript a programmed semi-helical tool path, on a plate with the following dimensions: 1,5mm of the thickness and 400x400mm of area.

The influence of the choice of these parameters was made by the use of sine law, $t_f = t_0\,(\lambda)$,where t_1 represents the wall thickness after forming, t_0 the original wall thickness and λ angle described by the initial configuration of the plate and the deformed surface.

In which it works to obtain the minimum possible of residual stress, what could cause a failure in the material during stamping. The conformability of the material is directly connected with the tool speed and radios, that occurs only on the point of contact. The stampability is directly connected with the friction generated between the tool and the plate.

In the figure below, it is observed the tool path contours based the required geometry.

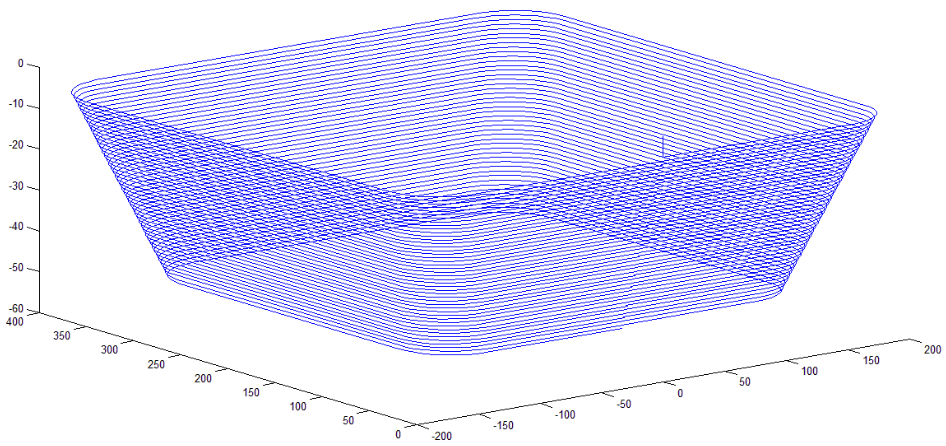

Figure 2-Tool Path Contours

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2.3 Finite element method

Numerical simulation by finite element method has a great consistency on the results of stamping a process, where possible to predict with reasonable reliability the initial and final condition of the process.

All the conformation processes generates modification on the properties of the materials and the geometry of the original die. For this work, were realized numerical simulations with non-linearity. For this work it was used explicit integration in the loading and formulation robust enough to treat with material and geometrical non-linearity. On the stamping process the plate was clamped on its edges, restricting all the rotational and translational movements, while that the puncture performed the stamping, it was being restricted only by moments about all axes, thus, after it's done having the desired shape.

The properties of the materials were placed through the curve stress x strain, when action on the plastic and the elastic came up with the material density and modulus of elasticity. The components were modeled with plane elements (2D), with six degress of freedom per node and one point of integration. The stamping tool was modeled as na rigid sphere with a diameter of 12mm.

In the figures below, we observe the steps of ISF, being at the beginning, the middle and end of the tool path.

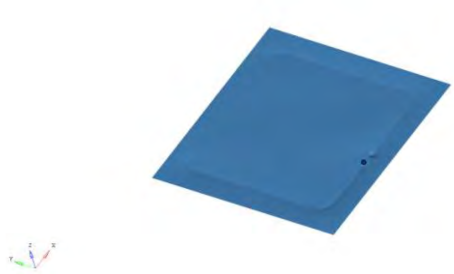

Figure 3-The first part of Simulation

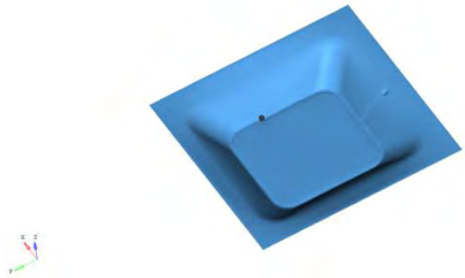

Figure 4-Middle part of Simulation

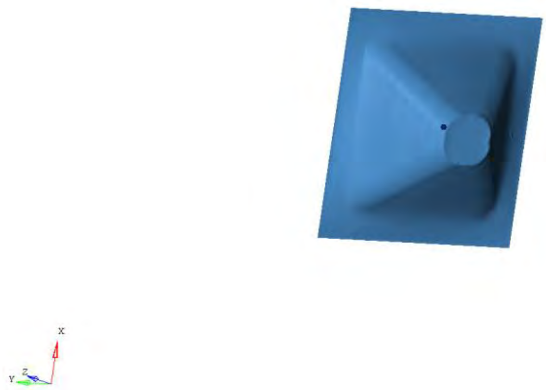

Figure 5-Final part of Simulation

3. RESULTS

Firstly the results that concern about the ISF process - thickness reduction and plastic strain - were analyzed. The ISF process differs from the conventional stamping processes because it provides great modifications on the thickness and strain hardening of the material, and the disregard of these parameters during its application could lead to considerable errors on the simulation results.

After were evaluated the following subjects: residual stress generated by the ISF process, comparison of the internal energies produced on the process, and the reaction force that the stamping tool suffered while it conformed the blank.

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3.1 Thickness and Plastic Strain Analysis

The results obtained showed that the DP and HSLA steels presented a thickness reduction very similar due that the stamping tool described the same predefined tool path and the reduction is is connected to the loads happened on each point, therefore the reduction is connected to the punctual loads.

The results on plastic stain displayed are also connected to the loads of the stamping process, and the forming tool the main factor for the occurrence of this fact. Is acceptable that both materials have a similar plastic deformation because the two processes had the same tool paths, and so the loads tend to be similar too.

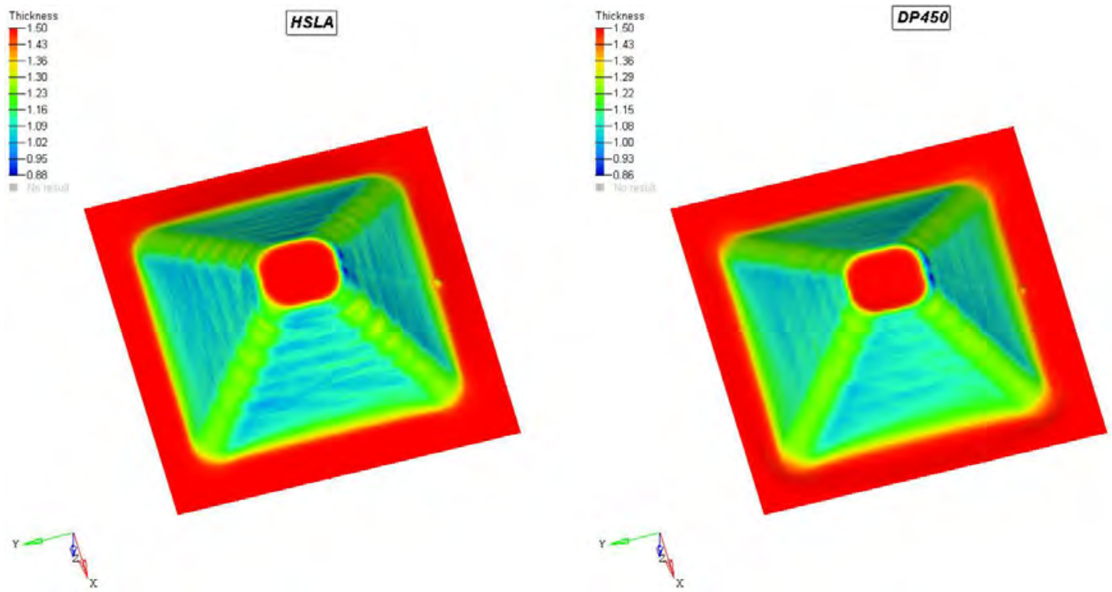

Figure 6-Thickness distribution for two steels

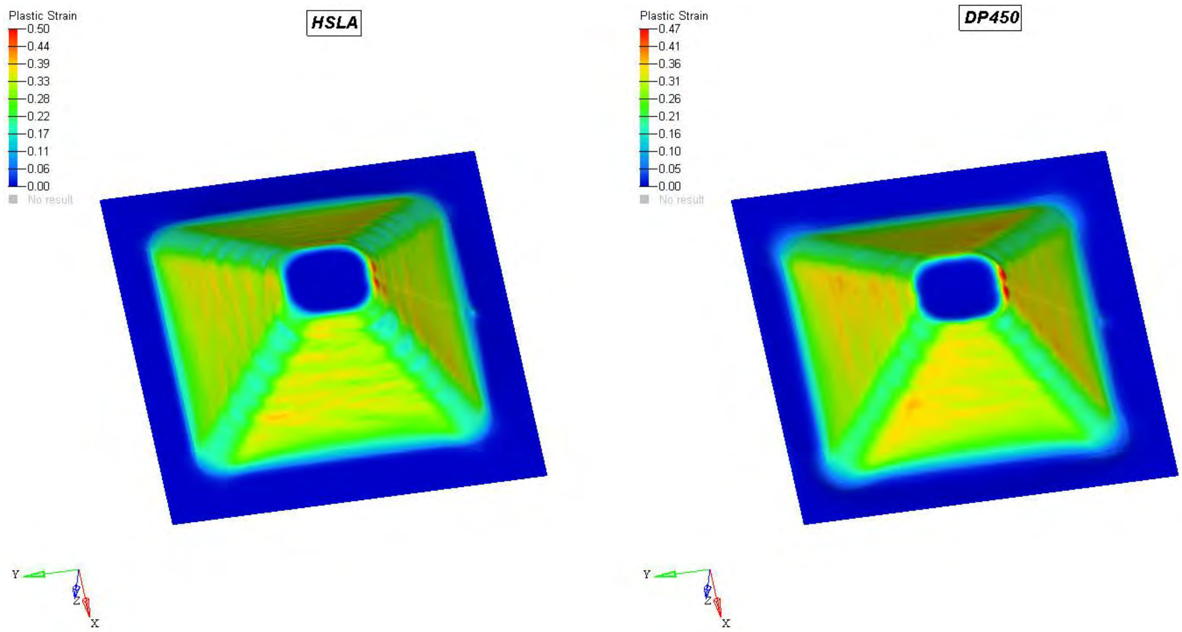

Figure 7-Plastic Strain

3.2 Comparision of Stresses

Figure 8 displays residual stresses that each material suffered after the ISF process, it can be noted that despite that the HSL steel had a yield strength grater than the DP450, during the process that occurs on the plastic Field of the material , this one has values of stresses lower than the values of the DP450. Because of the higher hardening rate of the DP compared to the HSLA, it can be observed that the Stamping process of The DP steel generated a greater difficulty to the tool to conform the blank, therefore the final part showed a greater values on residual stresses.

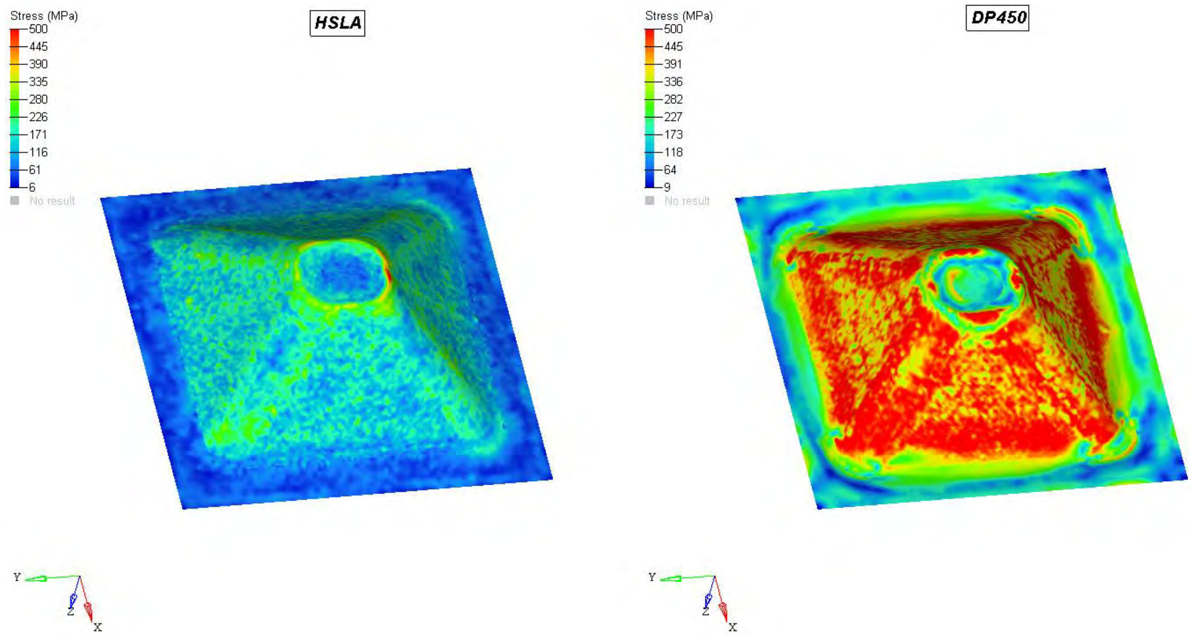

Figure 8-Stress contours

3.3 Force and Energy Analysis

Figures 9 and 10 show the analysis of the reaction force on the stamping tool and the internal energy generated in the process respectively.

Figure 9 it can be observed that the force on the forming tool during the stamping processing the DP steel varies around 7500 N while in the HSLA this force varies between and 5000 and 5500 N. On the DP this force is more elevated because of the hardening rate of it.

Figure 10 shows all the energy variation that occurred during the ISF. It is noted that during the beginning of stamping both energies are equal, because the materials are still in the plastic regime. After of efforts increase is noted that the DP450 curve has gradually increased its energy, because their hardening rate is greater. As HSLA has a yield stress greater than DP450 but after the elastic its voltage is lower than the DP450 their energy curve is lower.

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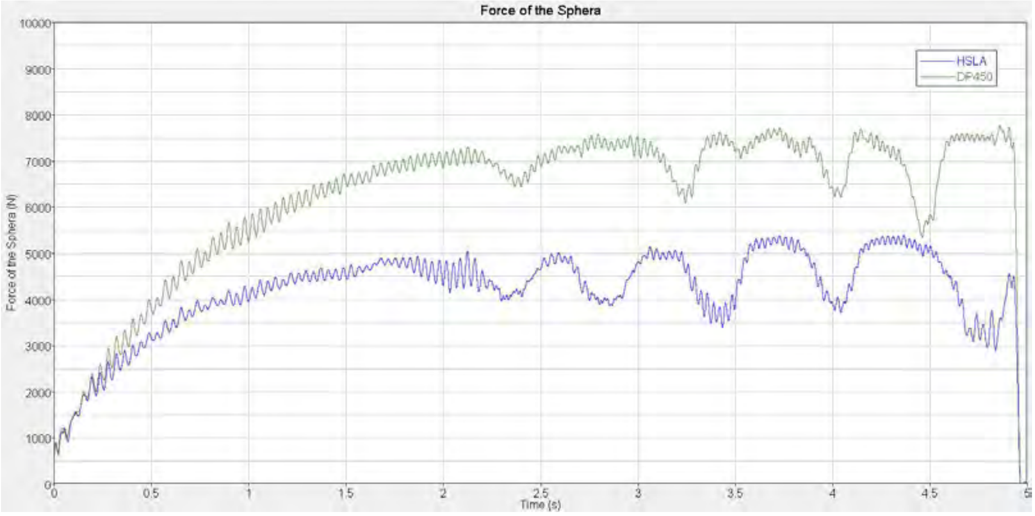

Figure 9-Force of the Sphera

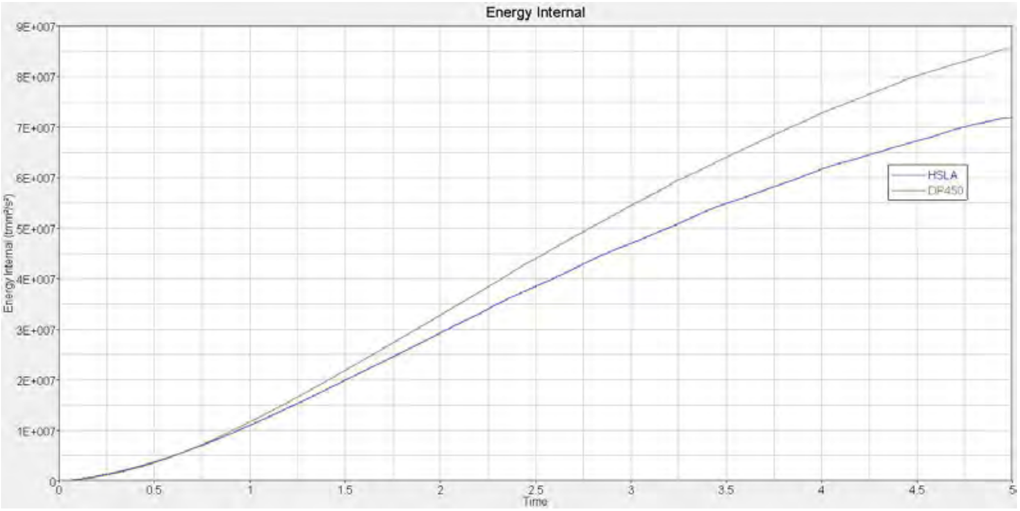

Figura 10- Energy Internal

4. CONCLUSION

This work evaluated, by numerical simulation, the use of incremental forming on two types of steels with same strength class, but with different hardening rates: a DP450 and a HLSA. Preliminary results have showed that despite the loss of stiffness caused by reduction of thickness during the incremental forming process, the high hardening rate of DP450 can provide structural benefits to the final component. A recent forming process, known as Incremental Sheet Forming (ISF), has produced encouraging results. It is based on the use of a spherical tool that deforms punctually a plate through a predetermined path. This process, which can be done on a CNC machining center (eliminating the expensive presses and dies of conventional process), reaches levels of strain above those achieved by traditional sheet forming, making it ideal for the manufacture of parts with complex geometry. However, depending on the inclination of the deformed surface, the thickness reduction can be quite high, exceeding 50%, which did not occur in the simulations. Although DP steels having yield stress smaller one than the HSLA may be noted that during the process, is required a higher energy process to occur due to their high work hardening rate, causing its residual stresses are greater in relation to HSLA having a high yield strength but the plastic part they have a low work hardening rate and causing the energy to be less conformation. Also noted that in the puncture ISF held a greater force on the plate DP450, due to high work hardening rate of the material, resulting in greater difficulty in puncturing the work done.

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