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NUMERICAL SIMULATION AND ANALYSIS OF THE TOOLS RADIUS AND DIFFERENT BLANK HOLDER FORCES INFLUENCES ON SPRINGBACK

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Abstract. *Sheet forming is the process of mechanical transformation that consists in assigning to a given material of characteristics and defined thickness, a final format given by a matrix. Among all possible processes, the deep drawing is an option commonly used in the automotive industry. For a long time, the concern generated by this process revolved around the elimination of necking and cracks during the process. Controlled these effects, another challenge arises interfering in the dimensional quality: the springback. This problem causes dimensional inconstancy and geometric distortion, which can cause certain problems in the assembly, or else make it impossible to assemble the shaped components. With technological advances, increasingly accurate simulation software greatly helps to avoid wasting the time and costs involved in such surveys, which, without this assistance, should be done in a practical way with trial and error. The simulation can predict changes to decrease or eliminate the springback. In this work the influence of the blank holder force and the tools radius in the deep drawing was evaluated by numerical simulation, analyzing the springback for the steel DC 06 and the TRIP 800, using ABAQUS® software 6.12-2. It was verified during the simulation that in the larger tools radius and in smaller blank holder forces the springback presented more significant, whereas in smaller tools radius and larger blank holder forces the springback was less significant for both steels.*

Keywords*: Numerical Simulation, Metal Forming, Springback*

1. INTRODUCTION

The ability to predict the behavior of shaped parts in sheet metal is vital for tool fabrication and process prediction. It is a worldwide trend to increasingly seek to shorten the time of placing new products, with high standard of quality, in the market. This becomes a necessity in terms of competitiveness mainly in the industrial sector of home appliances and automotive. In the automotive sector, the main application is in the production of components. In the search for lighter and safer vehicles, the mechanical sector was encouraged to develop new materials. In this context, AHSS (Advanced High Strength Steel) appears. These steels have higher mechanical strength combined with good ductility. However, they suffer from manufacturing limitations, particularly about springback after the deep drawing process. The challenges of the formability of these steels in industrial applications are the main concerns applied to the useful life of the tool and the springback of the material. The latter case is pointed out in the literature as a recurring problem in the manufacture of stamped parts, which causes dimensional and geometric deviations in the production of structural components. Therefore the springback must be foreseen in the tooling itself, this phenomenon is not easily predicted since several process factors generate great influence, especially when using advanced high strength steel plates.

In recent years, studies have shown that springback is influenced by a combination of various tool and process parameters, such as: lubrication condition, blank holder forces, blank thickness, die radius, cut size, and can be seen in the works of Sadagopan and Urban (2003) and Livatyali and Altan (2001). Zhang et al. (1997) using the "V" profile bending test. These techniques provided great values of springback, allowing to study the sensitivity of the springback to the relation tool radius and thickness of the plate (R / t). In the studies of Second Haus (2011) in comparison of TRIP800 and DC06 studying the process parameters in the springback in edge bending, it was verified that experimental tests with larger tool radius and larger gaps between the punch and the matrix contribute for an increase of the springback in both materials, being more significant for the AHSS TRIP800 steel. Liu et al. (2002) studied the variation of the application of the force in blank holder to reduce the phenomenon of springback, according to the authors the correct application of force in blank holder is one of the most effective methods to solve the problem.

To analyze the springback applied in different materials and different process factors through computer simulation, in this work the Makinouchi (1993) test model was applied, which consists of the "U" bending test make by deep drawing using the ABAQUS® 6.12-2 software, in order to evaluate the influence of different tool radius and load variation of blank holder on the springback of DC06 and TRIP800 steels.

2. RETORNO ELÁSTICO

When the material is deformed plastically, under the effect of the tooling it undergoes dimensional and geometrical deviations after the removal of the forming forces or the clamping forces imposed by the tooling, this dimensional deviation of the shaped member is known as springback. Springback is caused by an elastic recovery of the material shown in stress-strain curves (Lajarin, 2012).

Figure 1 illustrates well the springback difference given in dissimilar materials. At the point "OA" presents a schematic of the true stress-strain curve for the high-strength steel, that when unloading occurs due to the removal of all external forces, following the young modulus of the material, the material returns to point "B", where "OB" is the permanent deformation (plastic deformation of the material) and "BC" is the recovery of the deformation (springback). The same happen for mild steel, less intense. Although this elastic deformation recovery is small, it can cause notable change in the geometric shape of the part.

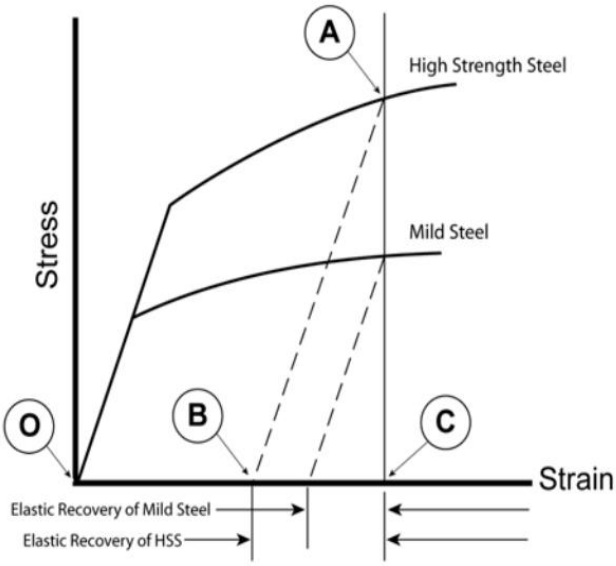


Figura 1 – Retorno elástico proporcional a tensão em diferentes materiais. (WorldAutoSteel, 2017).

The magnitude of the springback is described by the hardening model and the geometry of the component and the tool. When the geometry prevents complete relaxation of the elastic stresses during unloading, the stresses retained on the component are called residual stresses. These residual stresses released by the component or component change its final shape. If all tensile stresses can't be relaxed during stamping or deep drawing, geometric patterns can be created to assist in uniform distribution of stresses across the thickness of the sheet (Lajarin, 2012).

3. MATERIAIS E MÉTODOS

3.1 Material

In this paper, real data of DC06 steel plates and TRIP800 steel were used for computational simulations. To obtain the mechanical properties of the material was used the tensile testing machine EMIC DL10000 capacity 100 kN, located in the Laboratory of Materials and Surfaces of UFPR with sheet test bodies in the rolling directions 0º, 45º and 90º in sheet strips 12.5 mm wide by 200 mm long according to standard type-1 of NBR ISO 6892-1: 2013, a nominal deformation rate of 0.001 / s. The means of the mechanical properties of the material are presented in Table 3.

Table 1 – Mechanical Properties of DC06 and TRIP800 Steel.

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation L50 (%)	Density (g/cm³)
TRIP 800	525.08	860	209	22.6	7.87
DC 06	164.18	300.5	206	49.6	7.87

The procedures for determining the anisotropic properties of the materials were performed according to ASTM E-517. The length of the specimen was measured by means of a extensometer coupled to the specimen during the entire tensile test, also serving to control the deformation limit to be applied to the material. The measurement was performed by means of a digital paquimeter. With this data, the normal anisotropy coefficient ($\bar{r}$) was calculated from the mean anisotropy coefficient for each rolling direction (r0, r45, r90) and the planar anisotropy coefficient (Δr). These parameters are presented in Table 2.

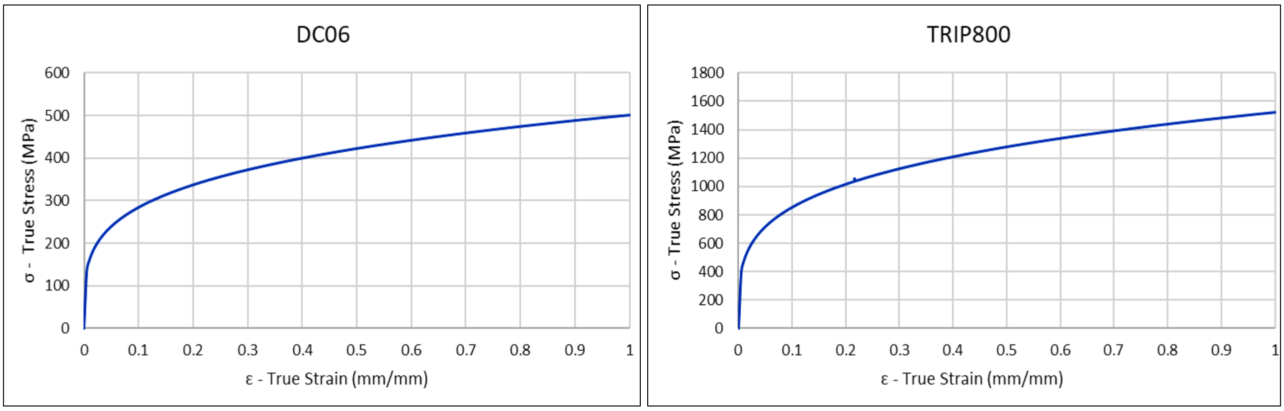
Table 2: Normal and Planar Anisotropy

Parameters	DC06	TRIP800
$\bar{r}$ – Normal Anisotropy	2.09	0.92
Δr – Planar Anisotropy	0.10	0.46

From the set of points obtained in the tensile tests in the rolling directions, were calculated the true stress - strain curves and generated the equations describing the elastic - plastic behavior of the materials. The coefficient of resistance (K), and the value of the hardening exponent (n), classified for steel DC06 in equation (1) and for steel TRIP800 in equation (2) was calculated. The curve that describes the elastic-plastic behavior of the materials is showed in Figure 2.

$$\sigma = 500.86\ \varepsilon^{0,246} \quad (1)$$

$$\sigma = 1463.2\ \varepsilon^{0,231} \quad (2)$$



(a) (b)

Figure 2 – True Tensile Strain Diagram. (a) DC 06 and (b) TRIP 800

To account for the anisotropic behaviour of the DC06 steel and TRIP800 steel, Hills anisotropic yield criterion was used to model the material behaviour in cup drawing. In ABAQUS, anisotropic values are required in the form of stress ratios which represent the ratio between reference yield stress specified for the metal plasticity and the measured yield stress value when applied as the only non-zero stress component. R11, R22, R33, R12, R13 and R23 are anisotropic yield stress ratios in six directions of the cube element. To represent the planar anisotropy, R11, R22 and R12 are important. The rest of the stress ratio values can be considered to be 1 for isotropic material behavior (equations (6)). The mathematical relations used to convert the strain ratios to stress ratios were required in Abaqus to account for planar anisotropy, showed in equations (3, 4, and 5):

$$R_{11} = \sqrt{\frac{r_{90}(r_0 + 1)}{r_0(r_{90} + 1)}} \tag{3}$$

$$R_{22} = \sqrt{\frac{r_{90}(r_0 + 1)}{(r_0 + r_{90})}} \tag{4}$$

$$R_{12} = \sqrt{\frac{3(r_0 + 1)r_{90}}{(2r_{45} + 1)(r_0 + r_{90})}} \tag{5}$$

$$R_{13} = R_{23} = R_{33} = 1 \tag{6}$$

From the equations and anisotropy coefficients of the DC06 and TRIP800 steels of the Hill'48 anisotropy parameter calculators, Table 3. These data are required for a characterization of the material anisotropy in the numerical simulation application.

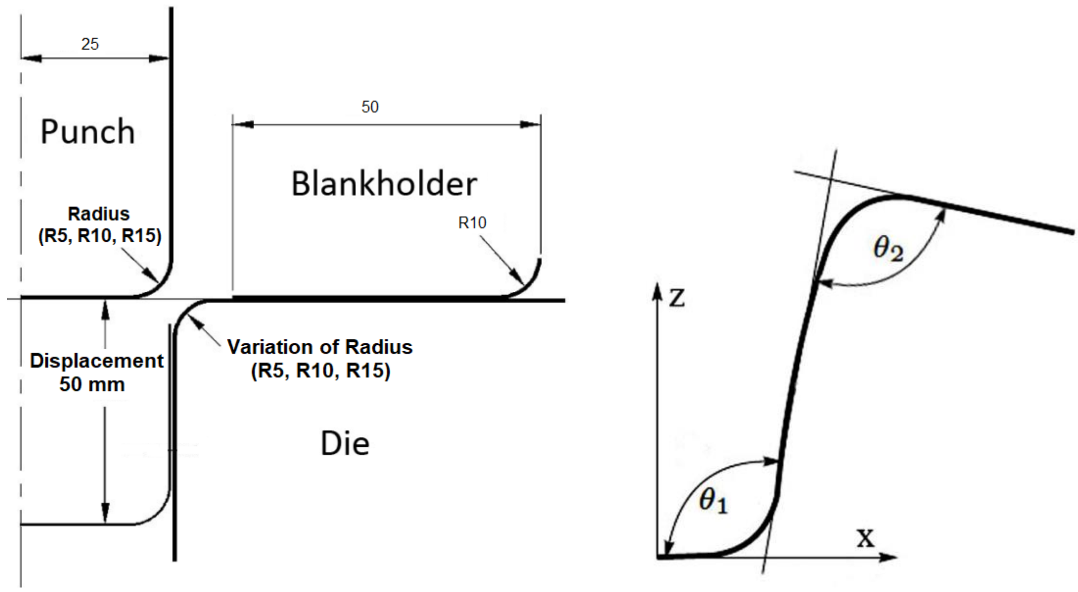
Table 3: Hill'48 Anisotropic Yield Parameters

Material	**R11**	**R22**	**R33**	**R12**	**R13**	**R23**
DC 06	0,967	1,158	1	1,042	1	1
TRIP 800	1,037	1,02	1	1,055	1	1

3.2 Embutimento

In order to analyze the influence of the tools radius on the springback, the simulated model comprises a die and a 50 mm diameter punch and 5 mm, 10 mm and 15 mm of radius, with a depth drawing of 50 mm, exemplified according to Figure 3a. For simulation, a 30mm x 150mm size blank of 1mm thick sheet was used in the materials for DC 06 and TRIP 800 steel. The gap between the blank and the tooling was 1.3 mm applied to the simulation. To measure the srpingback, the results were recorded and inserted in a CAD application, where measurements of the final bend angles θ1 and θ2 were performed. The two angles named θ1 and θ2 correspond respectively to the radius angle of the punch and the die, according to Figure 3b.

Besides the radius of the tool, the load variation of the blank holder forces was also evaluated in the springback. For this purpose, loads of 1 kN and 10 kN were used in the boundary conditions of the system to simulate blank holder forces and this effect for the two types of steel and the three-different radius of the tool.



(a) (b)

Figure 3 - Experimental Model Makinouchi (1993) with depth drawing 50 mm. (a) Tool Design and, (b) Springback Measurements Parameters

4. SIMULAÇÃO COMPUTACIONAL

The model applied to a simulation for a model like that applied by Woellner et al (2013) composed of punch, die, blank holder and blank. In the construction of the computational model, we used or symmetry procedure composed of punch, die and blank holder as rigid analytical elements and the blank as deformable element (Figure 4a). Since the sheet metal thickness is insignificant compared to its length and width, a shell element S4R and nine points of integration along the thickness of the sheet were used by the application explicit integration method. In the mesh refining, 272 elements were used, with 232 elements applied in the drawing region. The traction test data were assigned to the model with Hill'1948 anisotropic yield regime and isotropic hardening of the material.

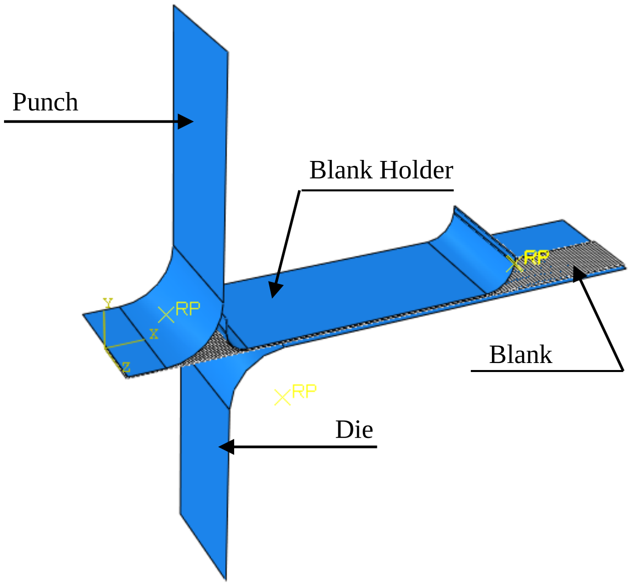
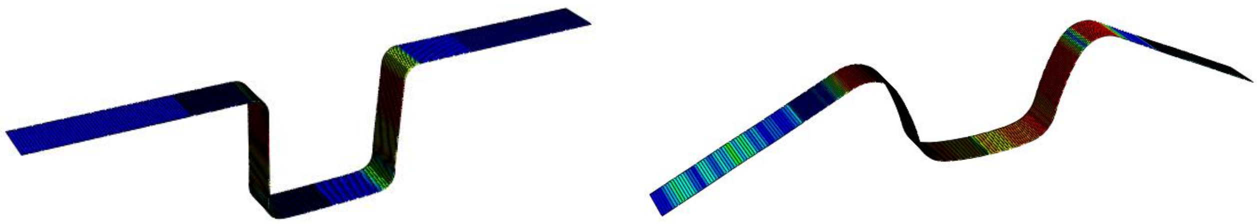


Figure 4 – Computational Model

The rigid body movements were controlled from the reference points (RP), and the contour conditions imposed on the tools were designed to describe the possible real experimental conditions. A Coulomb friction law combined with a penalty method was used to describe the state of contact. In this benchmarck a contact description was used by penalty and the friction value is 0.144 according to Lajarin (2012).

The simulation was divided into two parts. In the first part the deformation was developed with explicit dynamic model and in the second part the discharge was performed to verify the springback by the implicit static model. In this study, the instantaneous tool release method was selected for the present model, generating a change in the shape of the plate after removal of all the contact conditions, balancing the residual forces in the model. Figure 5a shows a simulated explicit dynamic model for the drawing with the ideal geometry, and Figure 5b shows the implicit static model simulated with the unloading, showing the springback.



(a) (b)

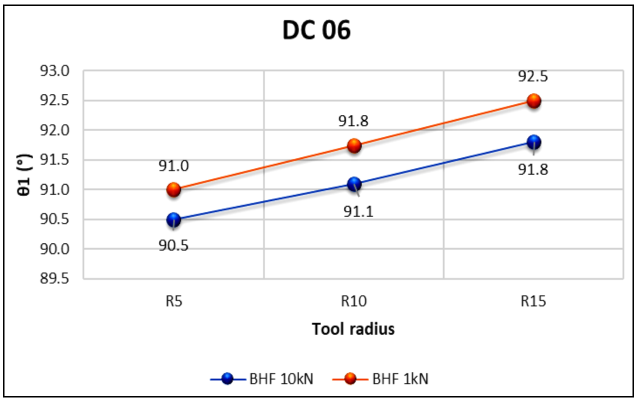
Figure 5 - Computational Response. (a) Explicit Dynamic Model with Ideal Geometry; (b) Implicit Static Model with Springback

To measure the springback simulated, the implicit static model was saved in 3dxml format and inserted in a CAD application, where analytical measures were performed at the final bending angles θ1 and θ2, in accord of figure 2b

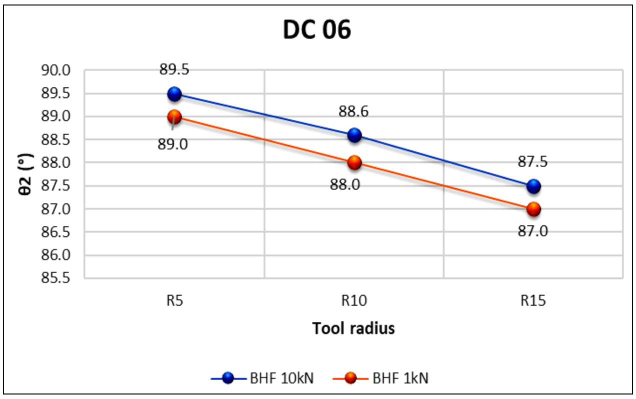
5. RESULTS

5.1 Springback

The simulated of springback values for the angles θ1 and θ2 for the DC 06 steel are obtained in the graph of Figure 6a and 6b. this graphs showed the increase of the tool radius increased the springback to the angle θ1 and θ2, generating different angles of the ideal (90º), for both blank holder forces (1kN and 10kN), the increase of the load of the blank holder forces simulated, provided a small reduction of springback for both the angles θ1 and θ2.



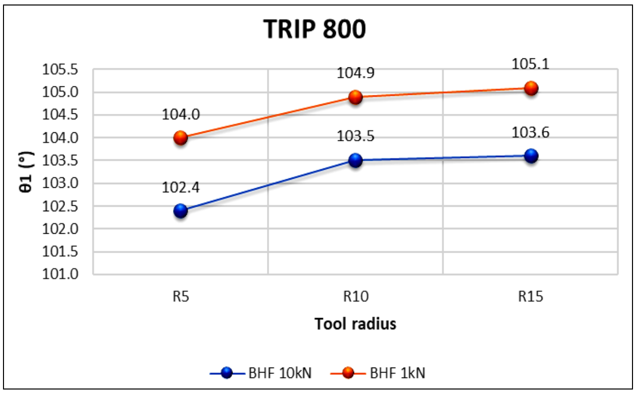
(a)



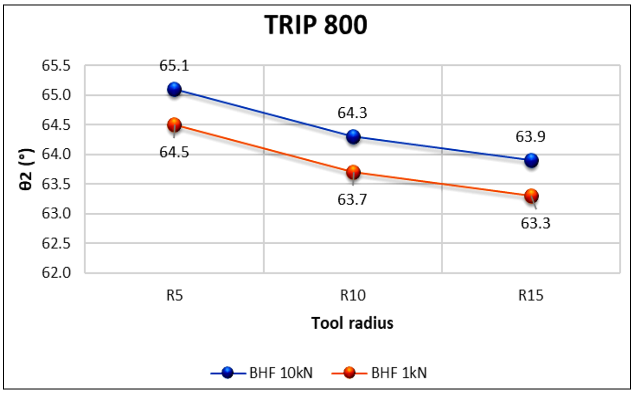
(b)

Figure 6 – Influence blank holder forces and tools radius: (a) angle θ1 for the DC06 steel; (b) angle θ2 for the DC06 steel

Similarly, for the TRIP steel 800 the simulated springback values for the angles θ1 and θ2, shown in Figure 7a and 7b, the increase of the tool radius increased the springback values for both angles θ1 and θ2, generating different angles of the ideal 90º, in different blank holder forces. It was also noted that increasing the load of the blank holder forces simulated, provided a reduction of the springback.



(a)



(b)

Figura 7 – Influence blank holder forces and tools radius: (a) angle θ1 for the TRIP800 steel; (b) angle θ2 for the TRIP800 steel

Comparing the two computationally simulated steel, it is possible to observe in Figure 6 and 7 that the magnitude of the generated springback is higher for the Advanced High Strength Steels TRIP800 (Figure 7) than for the High Formability Steels DC06 (Figure 6).

6. CONCLUSION

Analyzing the behavior of the materials and the different process parameters through springback numerical simulation, concluding that:

- The model responded with quality to the behavior of the material according to the simulated parameters.
- In simulation, the steels with higher mechanical strength compared to steels with lower mechanical strength. The TRIP800 steel with higher mechanical strength showed higher springback in accordance with the literature. Thus, requiring more attention regarding the processes employed with this steels.
- With respect to the tools radius, 5mm,10mm e 15mm simulated, the springback showed that in largers radius, the springback is more significant for both low strength steels than high strength steels.
- For blank holder forces, 1kN and 10kN simulated, the numerical results showed that higher forces help reduce the springback for both materials.

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8. RESPONSIBILITY NOTICE