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Analysis of Elastic Recovery in The Process of Bending Sheets of Duplex Steel SAF 2205 via Experimental Method and Numerical Simulation

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Abstract**—***The mechanical conformation is widely used in metal materials manufacture, being the bending process one of the most applied in the metal-mechanical industry. The material behavior analysis is important in this kind of process, since fabrication problems can compromise the final performance of bent components. During the bending process of metal sheets, the sheet undergoes a geometric variation after the withdrawal of the load. This effect, as known as elastic recovery, can be harmful when it is needed to fit two components with low tolerances. The comparative between elastic recovery problem analyses in folded sheets by numerical simulation and the experimental method seeks to anticipate possible inconveniences and additional costs during the try out tests. The numerical results are compared with the experimental laboratory tests. The contact and the interaction between the tool components and the sample boundary conditions are evaluated. Thereby, we consider the aspects necessary for modeling the elastic recovery in agreement with the experimental test, obtaining a very close result between the two methods.*

Keywords— Bending, Elastic Recovery, SAF 2205, Numerical Simulation.

I. INTRODUCTION

The bending forming process of sheet metal is one of the most applied in the metalworking industry. A large part of objects manufactured from sheet metal applies some kind of bending process (Sales, 2013). The elastic recovery consists of dimensional and geometric changes in the material. Those changes happens due to the withdrawal of the mechanical stresses necessary to perform the plastic deformation. This phenomenon depends of several factors, such as friction, lubrication conditions and operation geometric characteristics. However, aspects related to the material structural characteristics, such as the micro structural arrangement of the sample in terms of constituents and phases, grain size, possibility of possible phase transformations during the stamping cycle itself, among others, also seem to influence the results, since in the plastic deformation occurs the hardening of the material, providing increase of resistance (Sales, 2013). Fig. 1 illustrates the main parameters associated with a single process: the bend radius R, is generally expressed in multiples of the thickness, the bend angle α, the fold width b and the thickness of the sheet t.

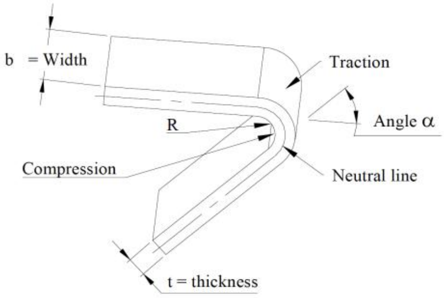

Fig. 1: Main parameters in sheet bending

The elastic recovery and the tooling involved in the manufacture of bending parts are important concern in the final dimension components design. They directly influence in productivity and costs. The increasing demand of automotive industry, which requires the increasing in use of steels with high mechanical strength, has led to an increase in the use of advanced high strength steel (AHSS)

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as working material (Schaeffer, 2004). The increase in the material flow stress decreases its formability and increases the elastic recovery. For this paper were performed tests of SAF 2205 material as received and after a heat treatment at 1050°C (Martins and Forti, 2008, pp. 162-166). The elastic recovery effect is one of the main factors that determines the final shape of the product, if it is not properly controlled it can affect the accuracy of the product. The present work evaluates the comparative elastic recovery of the experimental process using the mathematical modeling ABAQUS/CAE 2017 software of stainless steel SAF 2205 in V bending.

Duplex stainless steels are characterized by the presence of ferritic-austenitic biphasic structure (hence also referred to as austenitic). This leading to good combination of the properties of homonymous stainless steels, such as good corrosion resistance and toughness and high mechanical strength (Sales, 2013). These alloys currently represent an important class of materials and have been widely used in several sectors some example are the chemical, petrochemical and nuclear industries (Michalska and Sozanska, 2006, pp. 355-362).

In terms of chemical composition, duplex stainless steels have chromium and nickel contents ranging from 17% to 30% and from 3% to 13%, respectively, as presented in Table 1 (Krauss, 2005). It is important to emphasize that the steel SAF 2205 or UNS 31803 (0.03% C maximum, 21.00% -23.00% Cr, 4.50% -6.50% Ni, 2.50% -3.50% Mo; 0.10% -0.22% N) is the most used duplex stainless steel in industry nowadays, corresponding for about 80% of the world production of austenoferritic stainless steels.

Table.1 – Chemical composition of the material used and SAF 2205 technical specification, Wt %

Element	C	Cr	Ni	Mo	Mn	Si
Material used	0,026	22,67	5,32	3,02	1,85	0,37
Technical specif.	0,03	21 23	4,50 6,50	2,50 3,50	--	--

Despite the advantages when compared to other groups of stainless steels, a number of technical limitations are observed in austenitic steels, especially in relation with thermal cycles or thermo mechanical processing during manufacturing operations. These limitations are associated to the possibility of development of secondary phases, which would lead to the loss of properties, such as reduction in corrosion resistance and toughness (Fargas, Anglada and Mateo, 2009, pp. 1770-1782). The compounds presented in these secondary phases are carbides, nitrides and intermetallic compounds.

The technological clarifications due to scientific foundations in the bending process area are relatively new. Bending is an operation where a metal is folded, during this process the outer surface is drawn and the inner surface is compressed. These tensions increase from a neutral internal line, reaching the maximum values for traction in the outer layers and the maximum value for compression in the inner layer (Moro and Auras, 2006, pp. 24-27).

Once the bending effort has ceased the part of the section that has been subjected to tensions below the proportionality limit tends to recovery to the initial position, this phenomenon is called elastic recovery (Moro and Auras, 2006, pp. 24-27). Some material sections are submitted to tensions below the proportionality limit because it has stayed in the elastic region.

In the material deformation zone only the elastically region is capable to recovery. This phenomenon is very common in the bending process, it happens when the energy is redistributed for the entire piece through the internal balance, which generally causes a distortion in the material geometry, specified in the project. Therefore, the final shape of the piece do not depends only from the geometry of the die / punch assembly but also from the amount of elastic energy accumulate. Quantifying this portion of energy is a difficult task because it is influenced by many factors, including the adopted material model. On the other hand, an accurate prediction of the elastic recovery helps to size the tooling still in the design phase avoiding the trial out step and also error during the manufacture and final assembly of folded components (Sales, 2013). Several methods have been proposed to quantify or evaluate the elastic recovery of metals in sheet bending. A common method of elastic recovery intensity analysis is the determination of the K index. In this method is used the angles before and after the elastic recovery α_i and α_f or the radius R_i and R_f, according to Equation 1 (Dieter, 1981). Other techniques consider the relationship between the radius before and after the relief of the bending force. Among these methods, some also involve information on the characteristics of the material, such as modulus of elasticity, hardening exponent and Poison's coefficient, among others (Dieter, 1981). The mentioned approaches can be observed in Equations 2 to 4.

$$K = \frac{\alpha f}{\alpha i} = \frac{Ri + t/2}{Rf + t/2} \quad \textbf{(1)}$$

$$\frac{Rf}{Ri} = \frac{180 - \alpha f}{180 - \alpha i} \quad \textbf{(2)}$$

$$\frac{Ri}{Rf} = 4\left(\frac{Ri\ L_E}{E\,t}\right)^3 - 3\left(\frac{Ri\ L_E}{E\,t}\right) + 1 \quad \textbf{(3)}$$

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Where **E** is the modulus of elasticity of the material determined by the tensile test.

(4)

$$\frac{Ri}{Rf} = 1 - \frac{3\,k\,(1-\nu^2)}{(2+n)\,0{,}75^{\,(1+n)/2}}\left(\frac{2\,Ri}{t}\right)^{(1-n)} + \left[\left(\frac{2\,Ri}{t}\right)\left(\frac{k}{E}\right)^{1/(1-n)}\right]^3 x$$

$$\left[\frac{3\,(1-\nu^2)^{(3+n)}}{(2+n)\,0{,}75^{\,(1+n)/2}\,(1-\nu+\nu^2)^{(2+n)/2}} - \frac{(1-\nu^2)^3}{(1-\nu+\nu^2)^{1{,}5}}\right]$$

Where **k** is the coefficient of resistance, **n** is the harsh exponent and **υ** is the Poisson coefficient.

In general, the occurrence of spring back effect in metallic materials can be only controlled or minimized, since its complete elimination is considered extremely difficult (Abdullah at al, 2012, pp. 195-205). In order to minimize this phenomenon usually it works with a radius of curvature smaller than the planed one, so after the stress relief the elastic recovery inputs the final radius and it will be similar to the radius previously planned (Dieter, 1981). Once that the magnitude of the elastic recovery is known, the sheet can also be bent at large angles than required. In addition to the techniques mentioned, which may need to perform many tests, since they are empirical, there are other methods described in the literature. Some of these procedures are the application of high compressive forces, performing stretch and bend process at the same time and performing bend operations at elevated temperatures, since the slump in the yield stress leads to a reduction in the elastic recovery (Tekiner, 2004, pp.109-117).

II. EXPERIMENTAL PROCEDURE

The V bending matrix tests were performed in a hydraulic press using the tool developed at a 90° angle α, the opening of the bending cavity was 20mm and all tests were extended until the contact of the specimens with the surface internal of the V regions of the matrix. Subsequently, the force is interrupted, the specimen is withdrawn and the angle α' is measured with the aid of a degree transfer. The punctures rays ranged from 2 to 10mm with intervals of 2 mm. Each specimen measuring #1.9 x 19 x 49mm (Sales, 2013).

The specimens were taken from SAF 2205 sheets as received after a heat treatment at 1050°C (SAF 2205TT), with a 60 minute soak time and cooled in the air, in order to remove eventual characteristics printed by previously mechanical process. It is important to point out that this process was performed without promoting the development of intermetallic compounds (especially in the case of duplex stainless steel). The schematic drawing of the tooling and sheet is shown in Fig. 2.

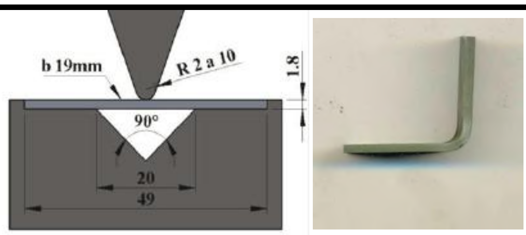

Fig. 2: Schematic drawing of the tools for bending of V-sheets and part sheet.

The analysis by mathematical modeling had used the same tooling profile with punch / sheet / matrix interaction with friction coefficient of 0.2. The punch and matrix were considered completely rigid. The deformation in full were attributed to the sheet. The elastic and plastic deformation parameters were defined in tensile tests and performed in the material as received (SAF 2205) and after suffer heat treatment (SAF 2205TT), according to table 2.

Table 2: Mechanical Properties of Duplex Steel SAF 2205 obtained from the tensile tests

Material	Elastic Module	Elastic Limit	Tensile strength	Strain ε	Coefficient Poisson
SAF 2205	175GPa	620MPa	806MPa	25%	0,29
SAF 2205 TT	170GPa	525MPa	754MPa	38,5%	0,29

For the contact between components, the contact algorithm was applied. It was chosen suitable parameters with a large refinement mesh in this contact region. In Fig. 3 is shown the mesh of the expanded matrix / sheet / punch assembly with its symmetry planes. The matrix and punch materials are considered rigid.

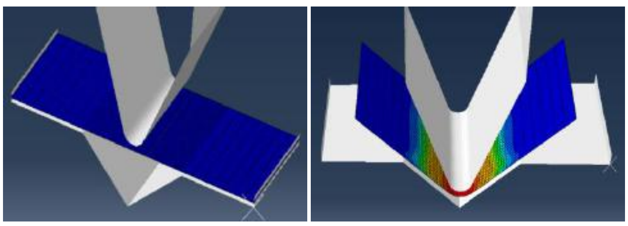

Fig. 3: Shell mesh for the finite element modeling.

In the modeling of the bending process a displacement in the punch is imposed. Thus, when the applied loading is removed the sheet assumes the punch and matrix geometry without happens the thinning of the thickness. After apply the loading, the stresses initially load are removed, leaving the sheet geometry with the shape of the new deformation. After this step the boundary conditions are applied to allow the recovery. The sheet material is considered completely elastic.

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The initial displacement and recovery steps are repeated for all punch radius settings (2, 4, 6, 8 and 10mm), changing the properties of the materials according to the tensile curves of the two specimens evaluated (as received and after the heat treatment at 1050°C).

III. RESULTS AND DISCUSSION

The outer bending surface of all parts was analyzed taking in consider the test conditions and the two states of the SAF 2205 material, as received and after the heat treatment (SAF 2205TT). According to the technique conducted, no cracks or other irregularities were observed resulting from the bending process. In terms of the materials characteristics, the material as received is the one with higher chance of cracking, since it still be influenced by the effects of previous mechanical operations (for example, hardening). In terms of the bending conditions, smaller bending radius represents the situation considered more critical, because they concentrate the greater tension in a smaller area, reaching values close to the tensile strength limit of the material.

Fig. 4 shows the distribution of the Von Mises equivalent stress on the sheet as received for the punch with radius R10 mm. This case corresponds to the end of loading and it can be noted that only the central region is in contact with the punch. It presents high stress levels reaching 759MPa, confirming the reason for no cracking on the external surface, since the values do not exceeded the material resistance limit. The major difficulty in this step was to ensure the convergence of the simulation due to the contact between the parties.

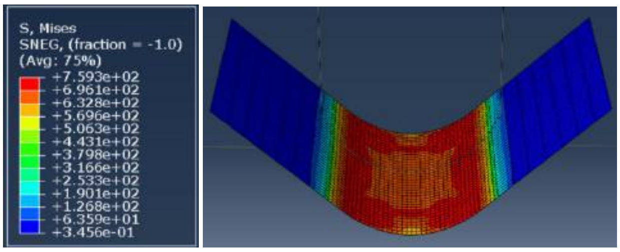

Fig.4: Sheet mesh R10 totally loaded.

After the displacement has been made, the punch return and the geometry of the sheet was evaluated by measuring the difference of angle α (90°) with α'. Fig. 5 corresponds to this new model and presents the distribution of the equivalent stress after the elastic recovery. In this case, there was a redistribution of the stress and their maximum values decreased to 432 MPa.

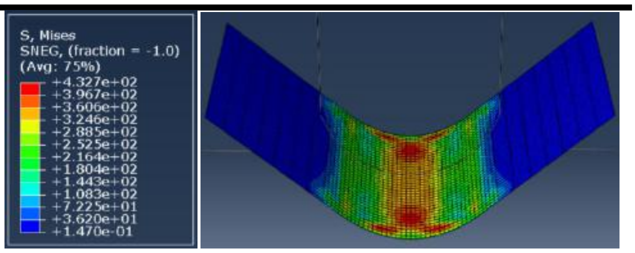

Fig.4: Sheet mesh R10 without loading.

For this specific simulation the value of variation of α after the withdrawal of the load was 346 minutes showing the action of the elastic recovery in the bending process. All results are described in Table 3.

Table.3: Differences between experimental and simulated angles in the elastic recovery of SAF 2205 and SAF 2205TT

Radio (mm)	Δ (α-α')min Simulation	Δ (α-α')min Experim.	Δ (α-α')min Simulação TT	Δ (α-α')min Experim.TT
2	309	340	254	235
4	315	345	270	240
6	320	367	306	267
8	330	392	320	302
10	346	420	324	337

Table 3 shows the values filled according to the bending radius for each condition of the analyzed material. It was verified that the increase in the bending radius raised the elastic recovery angle for both materials. The elastic recovery phenomenon became clearer for the SAF 2205 material as received in both situations, numerical and experimental tests. The differences between the numerical and experimental simulation increased as the bending radius raised from 9% to 18% in the 2 and 10 respectively, as shown in Fig. 6 for the SAF 2205 material.

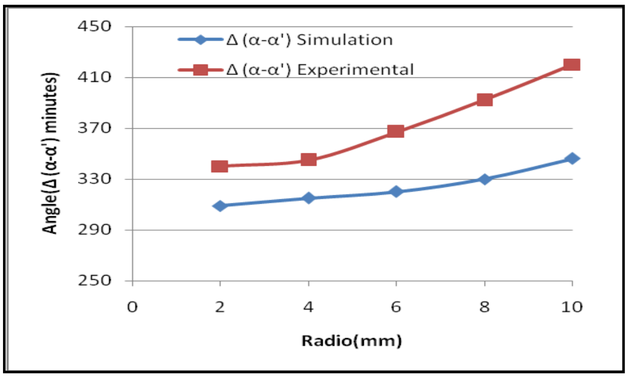

Fig.6: Radius x elastic recovery SAF 2205.

Similar to the previous data, the SAF 2205TT steel maintained the same tendency to increase the elastic recovery as the bending radius was increased. However, it presents a total inversion between the numerical

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simulation and the experimental test, showing the numerical simulation values higher than the SAF 2205, except for the 10mm radius. The elastic recovery differences in the SAF 2205TT steel were much lower when we compared both procedures, the fluctuations was between 4% and 12%, shown in Fig. 7.

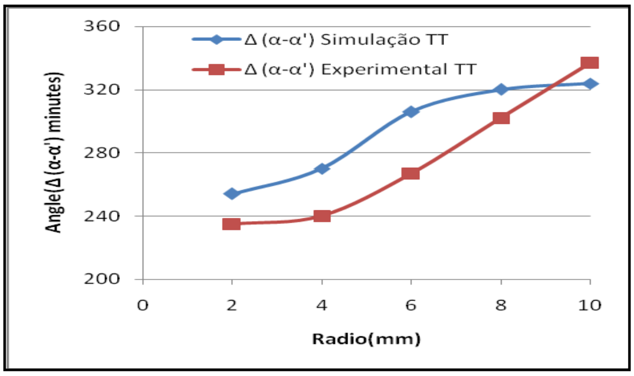

Fig.7: Radius x recovery elastic for SAF 2205TT.

The influence of the bending parameters on the elastic recovery phenomenon is an expected fact. This influence is constantly investigate for different materials and situations. The thickness of the sheet, bending radius, bending angle and width of the aperture of the matrix are indicated as the main geometric operation characteristics that can affect the results (Sales, 2013). Considering the approach of the present study, almost all the results obtained are in agreement with the literature, since it was observed that the increase in the puncture radius promotes an increase in the elastic recovery. Similar observations were presented in previous studies (Tekaslan, Seker and Osdemir, 2006, pp. 251-258).

In relation to the characteristics of the material to be formed, the flow limit and the modulus of elasticity are generally mentioned as the most significant parameters that affect the phenomenon of elastic recovery in bending (Tekiner, 2004, pp.109-117). The work suggests that a decrease in yield stress would lead to a reduction in the spring back effect (Tekiner, 2004, pp.109-117). On the other hand, smaller values of elasticity modulus would induce an increase in elastic recovery (Dieter, 1981). So the results presented in Figs. 6 and 7 are in agreement with previous studies. The parallel between the data obtained for the material as received with the one presented by the thermally treated material, associated, with lower flow limits, shows that the decrease in tension cited led to a reduction in elastic recovery. The data recorded from the material as received is affected by the hardening due to the previous plastic deformation during the sheet manufacturing process, so it will exhibit a higher flow limits (Table 2),

IV. CONCLUSION

In general, the numerical approach developed for both test conditions for the SAF 2205 steel were satisfactory, since they obtained results consistent with the experimental process and the reference literature. The elastic recovery phenomenon increased with the puncture radius and with the variation of the material properties.

The differences between numerical simulation and experimental testing were acceptable, with an average floating of 8%. This difference demonstrates that this method can be used as a reliability and cost reduction in the design of bending tools, since much of the time spent on try outs can be reduced with the bend angle correction been determined using the numerical simulation.

The same procedure can be applied in case where geometries are more complex, when an analytical solution or high cost in the experimental test makes impossible perform try out tests.

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REFERENCES

[1] Sales, V. (2013). Analysis of the Behavior of Stainless Steel AISI 304 and SAF 2205 in Different Conditions of Bending. *Masters dissertation*, Cefet-MG – Belo Horizonte, 115p.

[2] Schaeffer, L. (2004). Conformation of Sheet Metal. *Imprensa Livre Editora*, Porto Alegre.

[3] Martins, M., Forti, L. R. N. (2008). Effect of aging on impact properties of ASTM A890 Grade 1C super duplex stainless steel. *Materials Characterization*, v. 59, 162-166.

[4] Michalska, J.; Sozanska, M. (2006). Qualitative and quantitative analysis of σ and χ phases in 2205 duplex stainless steel. *Materials Characterization*, v. 56, 355-362.

[5] Krauss, G. (2005). Steels: Processing, Structure and Performance. *Materials Park, ASM Internacional*, 427 p.

[6] Fargas, G., Anglada, M., Mateo, A. (2009). Effect of the annealing temperature on the mechanical properties, formability and corrosion resistance of hot-rolled duplex stainless steel. *Journal of Materials Processing Technology*, v. 209, 1770-1782.

[7] Moro, N., Auras, A.P. (2006). Mechanical Conformation II - extrusion, drawing and forming of sheets; *Manufacturing Process Handbook*, Cefet–SC, 24 – 27.

[8] Dieter, G. E. (1981). Mechanical metallurgy. 2 ed. Rio de Janeiro: *Guanabara Dois*, 653p.

[9] Abdullah, A. B., Sapuan, S. M., Samad, Z. & Aziz, N. A. (2012). A comprehensive review of experimental approaches used in the measurement of springback. *Advances in Natural and Applied Sciences*, 2(2), 195-205.

[10] Tekiner, Z. (2004). An experimental study on the examination of springback of sheet metals with several thicknesses and properties in bending dies. *Journal of Materials Processing Technology*, v. 145, 109-117.

[11] Tekaslan, O., Seker, U. & Ozdemir, A. (2006). Determining springback amount of steel sheet metal has 0.5mm thickness in bending dies. *Materials and Design*, v. 27, 251-258.