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# ANALYSIS OF THE SPRINGBACK EFFECT WITH RESPECT TO RESILIENCE IN HIGH-STRENGTH STEELS APPLIED TO THE AUTOMOTIVE INDUSTRY.

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**Abstract.** *This work presents a study of the springback effect in four types of high-strength steels, wich are dual-phase, low carbon, bake hardening and interstitial free, currently used as raw material in the automotive industry. The mechanical properties of the materials were defined by means of tensile tests. Mechanical characterization of the springback effect was performed by means of mechanical forming trials, called three-point bending in air. From the curves obtained the bending test, was calculated for each sample, resilience in order to discover the energy involved in the elastic recovery of the material. Such calculations were contrasted with the statistical analysis of the springback effect for four degress of conformation: 30°, 60°, 90° and 120°. The results show that the springback effect on dual-phase steel, presents the greatest rates of springback due to greater resilience and the opposite occurs for interstitial free steel, the springback effect offers the lowest rates due to less resilience. Low carbon and bake hardening steels showed intermediate values in relation to other steels for springback and resilience values. Thus, it is concluded that the springback effect is related to steel capacity to absorb and release the energy used in forming.*

**Keywords:** *springback, resilience, high-strength steels, forming, three-point bending in air.*

## 1. INTRODUCTION

The burning of fossil fuels causes imbalances in the ecosystem, and so automobilistic industry has had the need to reduce more the weight of their products to minimize fuel consumption, thereby reducing the cost and possible environmental aggressions caused directly or indirectly by use of such products. Thus, the latest generation cars should have been lighter, economical, safe and environmentally cleaner (Gritti et al, 2002). Thus, steel industries, in response to their costumers have developed advanced high-strength steels (AHSS) in order to ensure the production of components with the same levels of mechanical strength, but with lower amount of material (Gorni, 2008).

However, the widespread use of AHSS in the automotive industry is limited due to challenges in formability, union sheet metal, tool life and springback. The springback is a major problem that compromises the mass production of automotive structural components with AHSS (Placidi et al, 2008).

The resistance of steel sheets is increasing in recent years, and the sheet of ultra high-strength steels with tensile strength higher than 1 GPa have recently been developed, however, currently most sheets are used in cars have tensile strength of 590 MPa or less (Mori et al, 2007) and use of the sheet of ultra high-strength steel is still limited due to the great springback.

The springback effect is indentified as a change occurred in the shape of the sheet after removal of the forming tool, due to redistribution of residual elastic tension (Keeler, 2009). Therefore, in order to find solutions to eliminate or reduce this effect, it becomes essencial to predict the occurrence of this effect during the component design correlated with microstructural and mechanical properties of the material.

Resilence (Ur) is the maximum deformation energy that a bar can absorb without suffering permanent deformation.

The term resilience means energy stored in elastic deformation in one body, that is developed when cease deformation causing tensions; i.e. it is the potential energy of deformation. (Medina, 1997).

Once the springback effect is a release of residual energy stored, and resilience is an stored elastic deformation energy, this work makes the comparison of the values of these energies.

The four types of steels studied in this work are among the major steel used by automobile industries currently because they are high-strength steels, they being dual-phase steel (DP), low carbon steel (LC), bake hardening steel (BH) and interstitial free steel (IF). Such materials have mechanical characteristics suitable for use in industry, but at the same time have dimensional problems due to the springback effect. Therefore, it is necessary a reproduction this effect by conformation tests most commonly used in industry for comparing them in order to reduce this effect.

The authors claim that the results of this work have never been disclosed in other previous publications.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Tensile tests

The specimens for tensile tests were made in accordance with the standard ASTM E8M, 2009. Tensile tests were performed in a universal testing machine of Shimadzu trademark, Autograph AG-X model 50 kN.

### 2.2 Tests mechanical conformation

Test specimens were made from the same material as received and sectioned at dimensions following: 80 mm long by 30 mm wide by 1 mm thick. Such dimensions of the specimens were made according to the parameters defined for the unconstrained cylindrical bending test presented at the Numisheet conference 2002 (Numisheet, 2002).

The specimens were subjected to a test called the three-point bending in air. This experiment was made in adapting the method unconstrained cylindrical bending test, in wich the specimen is subjected to a punch with the cylindrical body.

The punch was 5 mm radius and the distance between the supports of the die was 13 mm according to standards ASTM ID: E 290-09 to a sample thickness of about 1 mm. The three-point bending in air was performed in a universal testing machine of Shimadzu trademark, Autograph AG-X model 50 kN.

The specimens were subjected to conformation until the internal angle of bending reached a predetermined value. The values selected for the internal angle bending were: 30 , 60 , 90 and 120 degrees respectively for each bend, using three replicates for each angle in the same material. The punch was removed from the material 20 seconds after reaching the bending angle and then the measurement was made of the new bend angle to determine whether there was springback. For this measurement was used the software ImageJ 1.45 for processing images photographed on Olympus digital camera. Such measurements continue to be made for a period of 12 h, 24 h, 48 h and 72 h after forming. Completed the 72 h after mechanical bending, the angle bending resulting was subtracted from the initial angle of bending, which were 30 º, 60 º, 90 º or 120 º, and this subtraction resulted in total springback angle ($\theta 1 + \theta 2$), as shown in Fig. 1.

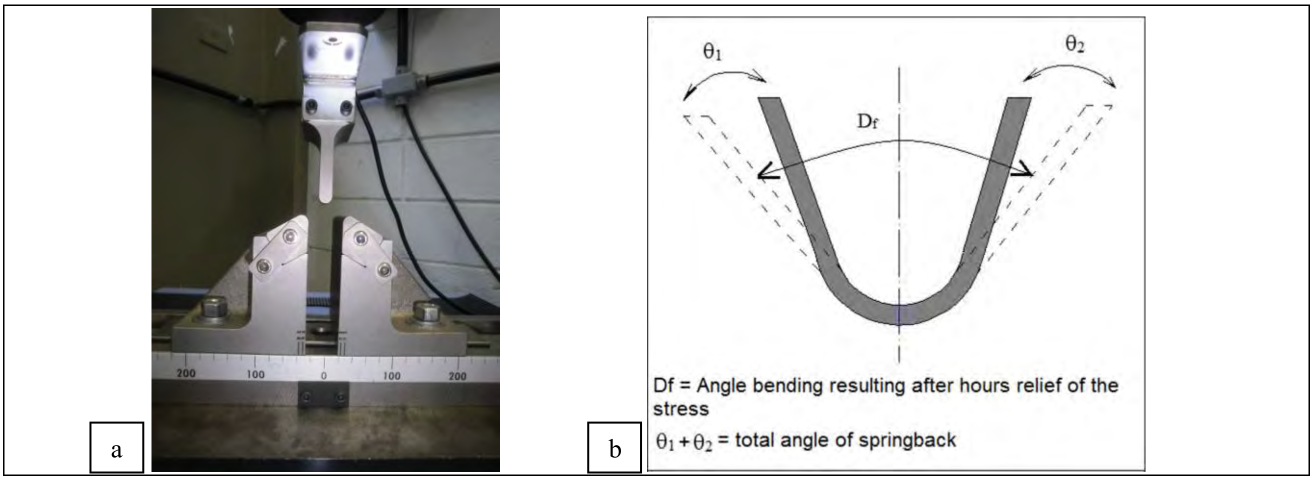


Figure 1. In (a): universal testing machine device fitted to the three-point bending in air. In (b): representation of a specimen steel sheet undergoing to the springback effect.

The Fig. 2 shows in (a) samples of sheets, for illustration, already subject to three-point bending in air and subsequent springback effect for 72 hours, where the numbers refer to the values of angles of bending applied, with (1) was 120°, (2 ) was 90° (3) was 60° and (4) was 30°. The Fig. 2 shows in (b) a scheme of measurement used in the software Image J 1.45 approaching the curvature for a triangle formed with the purpose of finding the springback angle.

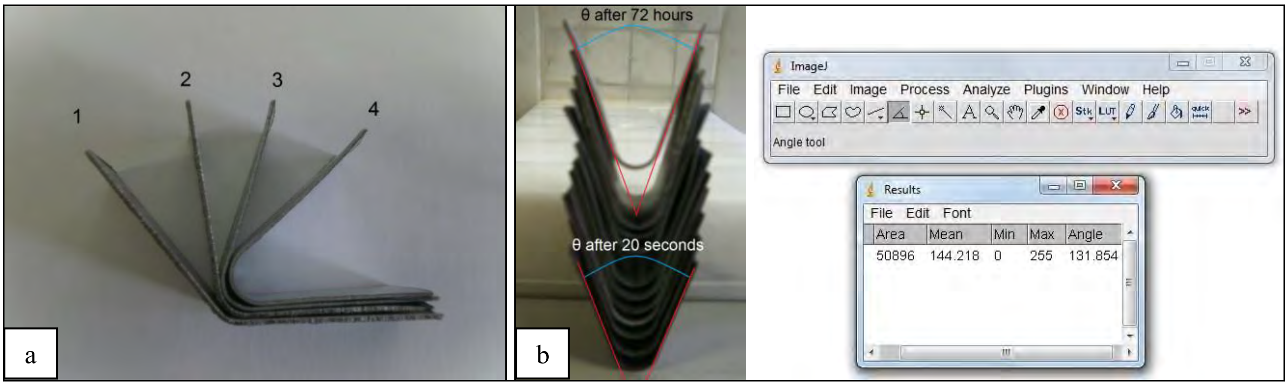


Figure 2. (a) Samples of sheets, for illustration, already subject to three-point bending in air and subsequent springback effect for 72 hours. (b) Angles obtained after springback effect measured in software Image J 1.45.

### 2.3 Statiscal analysis of the springaback effect and calculation of resilience

ANOVA was used as a statistical tool for interpreting the results of the springback effect. His name means analysis of variance and it is a test of comparison of averages the treatments, which in the present study, it was used two-factor ANOVA type with repeat submitted to the test F at a significance level of 5%. The software used for this function was Minitab 14.

For the calculation of the resilience energy, was used the Eq. (1), obtained from (Beer et al, 2006):

Equation 1:

$$U_r = (\sigma_e^2)/(2*E)$$

$U_r$ = resilience (KPa)
$\sigma_e$ = yield strength (MPa)
E = young´s modulus (GPa)

The values of $\sigma_e$ and E were obtained from Table 1.

## 3. RESULTS AND DISCUSSION

With respect to mechanical properties, their average values and standard deviation shown in Table 1 were obtained by tensile tests and 6 repetitions were made for each material. In the table, tensile strength is designed by RT in MPa, yield strength by LE in MPa, elongation by ε in % and Young's modulus by E in GPa.

Table 1. Mechanical properties of materials dual-phase steel - DP, low carbon steel - LC, bake hardening steel - BH and interstitial free steel – IF.

| Material | RT (MPa) | LE (MPa) | ε (%) | E (GPa) |
|---|---|---|---|---|
| **DP 600** | 623,6 ± 2,9 | 407,3 ± 3,6 | 23,4 ± 1,4 | 213,2 ± 2,9 |
| **LC** | 353,9 ± 0,7 | 232,4 ± 7,1 | 30,0 ± 2,2 | 190,5 ± 1,9 |
| **BH** | 320,9 ± 5,3 | 198,7 ± 3,9 | 33,4 ± 1,7 | 170,3 ± 3,5 |
| **IF** | 298,0 ± 2,1 | 147,9 ± 3,8 | 40,9 ± 1,9 | 200,7 ± 3,8 |

Figures 3 to 7, below, shows the statistical analyses of type ANOVA for springback values and the values of resilience.

In Fig. of 3 to 6, it is observed that no significant interactions between the factors of time and degree. Therefore, it can be said that the degree factor is independent of the time factor. It is observed too that there are no significant differences for the treatments with respect to the time factor.

In Fig. 3, is observed two groups of treatments significantly distinct. The 30° and 60° treatments differ statistically from 90° and 120° treatments. The treatments of 30° and 60° presented the greatest angles of springback, already the treatments of 90° and 120° presented the smallest angles of springback.

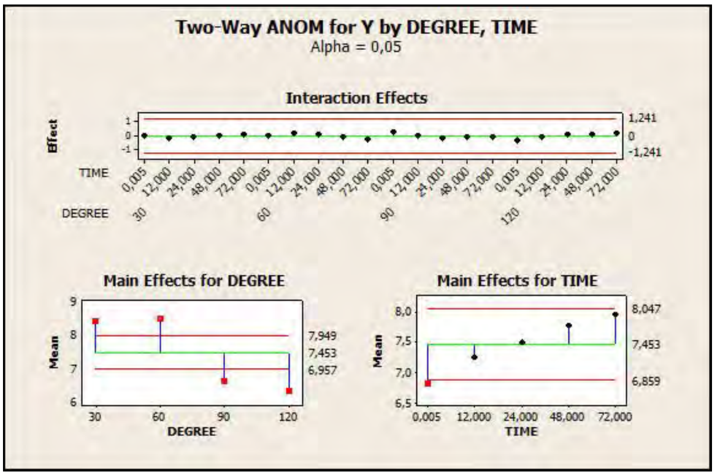


Figure 3. Effects of interaction between treatments degree and time, the main effects of the treatment degree and the main effects of the treatment time to a significance level of 5% for the dual-phase steel, with three repetitions per treatment.

In Fig. 4, with respect to the graph that presents the effects of treatments 30° and 60° were those who differed statistically from the others, showing the largest and smallest springback effect respectively. With respect to the 60° treatment there was a slipping on loading of the specimen during the bending test. This slipping damaged the loading of specimen in this treatment, causing the lowest effect springback.

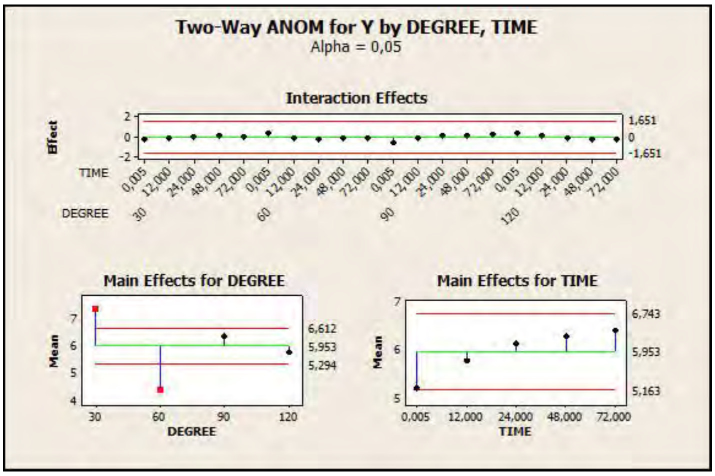


Figure 4. Effects of interaction between treatments degree and time, the main effects of the treatment degree and the main effects of the treatment time to a significance level of 5% for the low carbon steel, with three repetitions per treatment.

In Fig. 5, with respect to the factor degree influences the springback effect, it can be said that the 30° and 120° treatments were the most differentiated with respect to average, having their points exceeded limiting lines of deviations, showing the largest and smallest springback effect, respectively.

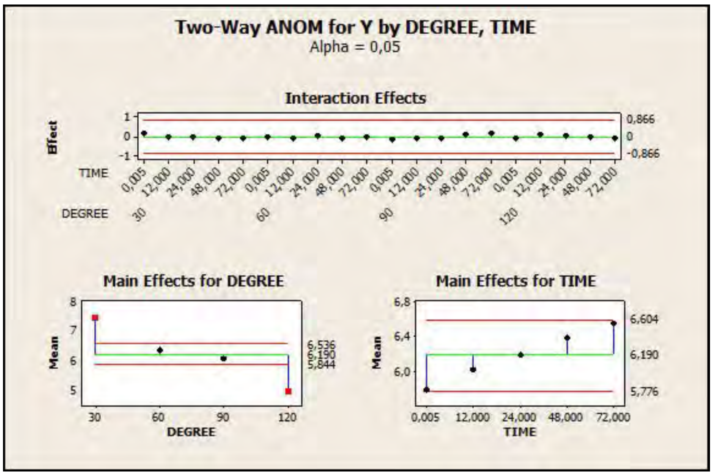


Figure 5. Effects of interaction between treatments degree and time, the main effects of the treatment degree and the main effects of the treatment time to a significance level of 5% for the bake hardening steel, with three repetitions per treatment.

In Fig. 6, the 30° treatment was the only statistically differentiated from the others, since your average is above the limiting line of deviations to a risk of 5%.

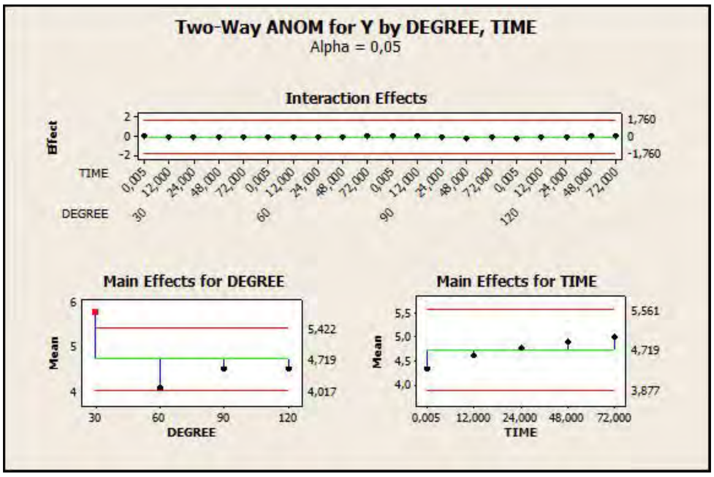


Figure 6. Effects of interaction between treatments degree and time, the main effects of the treatment degree and the main effects of the treatment time to a significance level of 5% for the interstitial free steel, with three repetitions per treatment.

Figure 7 shows the averages and standard deviations of the resilience values for each steel analised. It's possible to notice that resilience increases to the same extent that increases the resistance limits of steels. That is, the value of resilience for dual-phase steel is much bigger than the resilience to interstitial free steel, i.e, dual-phase steel is has the biggest resistance limits and interstitial free steel has the lowest limits of resistance among the materials studied.

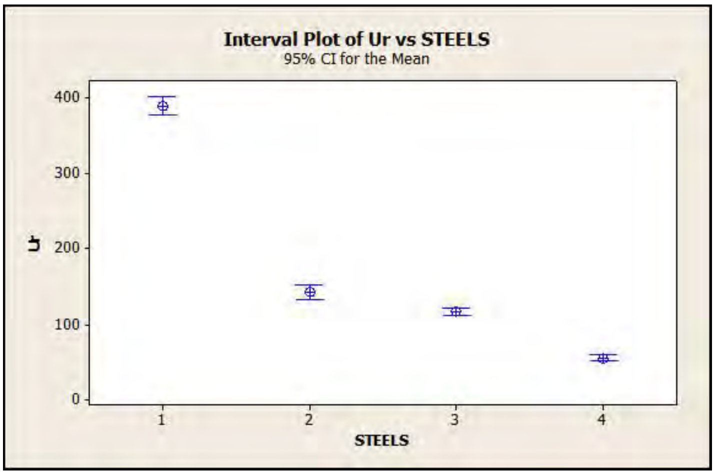


Figure 7. Analysis of variance at 5% level of significance by Minitab software 14 for the effects of the resilience in following steels: (1) = DP; (2) = LC; (3) = BH and (4) = IF; with six repetitions per treatment.

From the average values of table 2, it was possible to build the graph of Fig. 8 (a). And from the average values of table 3, it was possible to build the graph of Fig. 8 (b).

Table 2. Average values of springback angles for each degree of bending over the different steels studied. Values obtained using the software Image J 1.45.

| Steels | Bending angles | | | |
|---|---|---|---|---|
| | **30°** | **60°** | **90°** | **120°** |
| **DP** | 8,991 | 8,783 | 7,001 | 6,987 |
| **LC** | 7,817 | 4,705 | 7,082 | 6,006 |
| **BH** | 7,700 | 6,684 | 6,583 | 5,233 |
| **IF** | 6,010 | 4,415 | 4,709 | 4,856 |

Table 3. Values of resilience obtained from Eq.1 for each steel.

| Steels | **Ur = Resilience (KPa)** |
|---|---|
| **DP** | 389,29 ± 11,3 |
| **LC** | 141,86 ± 8,7 |
| **BH** | 115,94 ± 4,2 |
| **IF** | 54,63 ± 3,3 |

As shown in Fig. 8 (a), the dual-phase steel showed the greater the springback angle (between 7 and 9 degrees) and the interstitial free steel, which had lower angles (between 4.4 and 6 degrees). Thus, Fig. 8 (a) shows the results that can be compared with the W.Gan work, whereby it was concluded that materials with higher yield strength tend to have greater springback effect as compared to other materials with lower yield strength (Gan et al, 2006).

Also as shown in Fig. 8 (a), the angular variation of the springback effect was increased from 120° to 30° to the steels tested. This means that the extent that the internal angle bending was reduced, which were 120°, 90°, 60° and 30° respectively, occurred an increase in the springback effect, i.e. to the dual-phase steel, a decrease in the internal angle bending causes a greater springback effect.

In Fig. 8 (b) it is observed that resilience varies in this ascending order: interstitial free, bake hardening, and low carbon dual-phase. Note too that the resilience is greater for the most resistant steel as the dual-phase and lower to the less resistant steel as the interstitial free.

Both the Fig. 8 (a) and Fig. 8 (b) show the increasing values of springback effect and increasing resilience values in the same ascending order of steels as for the resistance limits shown in table 1.

Comparing Fig. 8 (a) and 3 (b), it is concluded that steel with a higher energy resilience showed the highest springback effect, i.e. as the resilience increases in ascending order of interstitial free steel for the dual-phase steel, the springback effect also increases in the same order.

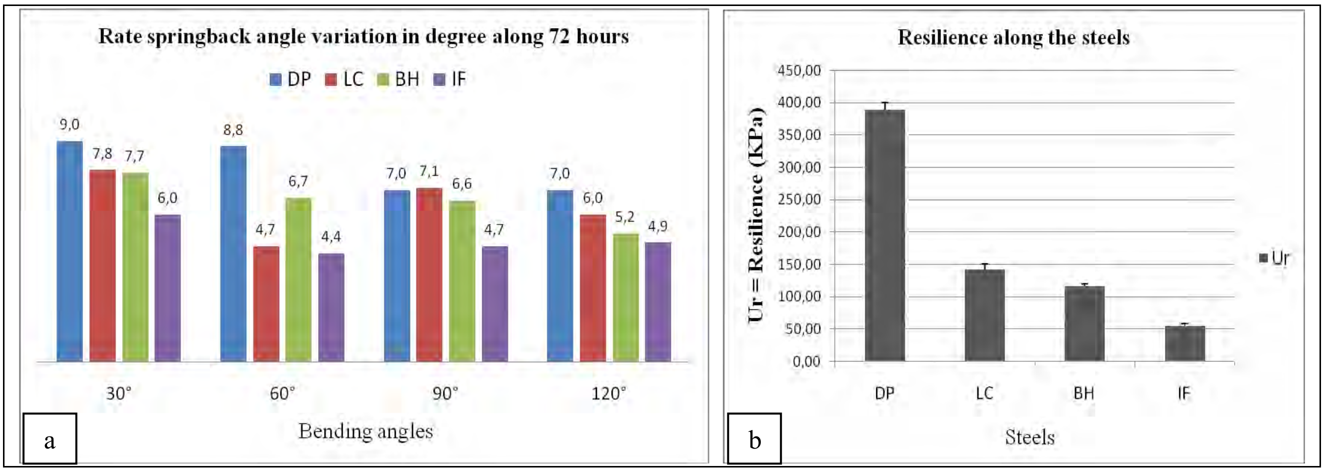


Figure 8. In (a): angle variation of the springback effect for each steel in different bending angles after 72 hours and in (b): resilience for each steel.

## 4. CONCLUSION

It is observed that as the limits of resistance increase, interstitial free steel for the dual-phase steel, there is also an increase in the values of resilience and a consequent increase in the springback effect. Thus, it can be said that the resilience and the springback effect are related to the limits of resistance of materials.

Note also that the springback effect increases as the severity of the bending angle becomes greater, because the material needs a greater amount of energy to get to the desired angle.

The springback effect is directly proportional to the resilience energy, since this energy is greater in the more resistant steels such as dual-phase and lower in more ductile steels, as in the case of interstitial free. Low carbon and bake hardening steels showed intermediate values of resilience.

Therefore, it can be said that the springback effect on advanced high-strength steels is closely related to resilience property of materials.

## 5. ACKNOWLEDGEMENTS

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