Springback comparison between DP600 and DP800 steel grades

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Abstract

A comparative study of the springback effect, otherwise known as elastic return, on Dual Phase DP600 and DP800 steel sheets is reported herein, which have been widely used in the automotive industry due to having good mechanical properties, such as high strength and ductility if compared to conventional steels. For such a purpose, it is proposed to analyze whether anisotropy and varying forming parameters interfere with the springback effect or not. The parameters selected to compare DP600 with DP800 dual phase steels were descending speed of 4 mm min⁻¹ along the vertical axis of sheets until reaching internal bending angle of 30 degrees during bending tests at two rolling angles (0 and 90 degrees), thus forming a U-shaped steel sheet. In addition to bending tests, tensile testing and Vickers microhardness tests have been performed at three rolling angles (0, 45 and 90 degrees). It was concluded that punching rate, internal bending angle, observation time and rolling angle exert an influence on the springback effect. Thereby, there is an important contribution to areas that require quality in formability, such as vehicle structure, which must have high impact strength and energy absorption. Steel sheets with increasingly smaller thicknesses are able to reduce density, product cost and greenhouse gases emissions from automobiles.

1. Introduction

Metal sheets have been widely used in automotive manufacture due to their good formability. Various quality defects (e.g. springback, wrinkling and crack) in metal sheets are induced after plastic assembly, including tensile, bending, drawing processes, and so on. Its precision is affected and the development of such forming technology is restricted thereof. Nowadays, due to the amount of high-strength steel applications, the springback effect has been attracting increased attention [2, 5, 6, 7].

The growing demands for reduced fuel consumption by the automobile sectors, stringent regulations designed to minimize environmental pollution, especially regarding greenhouse gas emissions, as well as an urge to reduce material and conserve financial resources, and recyclability issues have compelled the automotive industry to produce more fuel-efficient vehicles by weight reduction [1, 10, 12].

Dual Phase steels (DP), are materials which have low carbon content, being constituted basically by ferrite and martensite with insignificant content of retained austenite and bainite [4].

2. Methodology

In order to measure the springback effect, it was necessary to perform every metallography step and mechanical tests, such as bending, tension and Vickers microhardness testing.

2.1. Metallography steps

The metallography steps were performed in accordance with the ASTM E3-11 standard.
2.1.1. Sectioning
The specimen to be analyzed by electron microscopy was sectioned without undergoing microstructural changes by the used method. It was chosen to use the frozen sectioning method through a CNC machine, i.e. Computer Numeric Control, for tensile and bending tests.

For Vickers microhardness tests and metallography steps, specimens were sectioned by means of a vertical bandsaw machine, both from the Machining Laboratory at the São Paulo State University Júlio de Mesquita Filho, UNESP, Guaratinguetá, São Paulo, Brazil. The specimens for the bending test, metallographic analysis and Vickers microhardness testing measured $80 \times 30 \, \text{mm}$, $10 \times 10 \, \text{mm}$ and $10 \times 10 \, \text{mm}$, respectively. For tensile testing, dimensions were determined according to the ASTM E8/E8M standard.

2.1.2. Mounting
The metallographic mounting was performed using the hot mounting process in which bakelite and a metallographic mounting press were used in order to obtain a mounted specimen and achieve good results in the metallographic preparation, besides offering ease of handling for the next steps.

2.1.3. Sanding
Water sandpaper was used for sanding, which was attached to rotating disks in automatic sanding machines every three specimens at a time. It was performed on a MetPrep 3™ grinding and polishing machine by Allied High Tech Products, INC, at 300 RPM and 8 N of force for each specimen.

Normally, it is initiated by using a 180 grit water sandpaper, followed by 220, 320, 400, 600, 800, 1000, 1200, 1500 and 2000 grit water sandpapers. The whole sanding process is performed by running water cooling. Between the sanding steps, cleaning was performed by a manual 60 Hz stainless steel Ultrasonic Cleaner by Sanders at 40 kHz of ultrasound frequency and 120 W of consumption for 5 min. Specimens were immersed in running water and then mixed with detergent or 10% alcohol. They were dried by cold blast. Its quality was monitored according to the sanded surface using a STEMI 2000—ZEISS stereomicroscope at 50× magnification.

2.1.4. Polishing
Afterwards, polishing was also performed through a MetPrep 3™ grinding and polishing machine, Allied High Tech Products, INC, at 300 RPM and 8 N of force for each specimen. The machine allows polishing every three specimens at a time. It was performed by using OP-NAP polishing cloths glued to rotating discs on which small amounts of abrasives are deposited.

The abrasive selected for this work was colloidal silica, along with distilled water. Abrasives vary according to the type of metal being prepared. After polishing, the samples were cleaned by mixing water with detergent on a cotton pad which was then gently rubbed on the specimen, followed by cold blast drying.

2.1.5. Chemical attack
Nital is comprises a ratio of 1 ml of $\text{HNO}_3$ (nitric acid) with 99 ml of ethanol (ethyl alcohol) to 5 ml of $\text{HNO}_3$ (nitric acid) with 95 ml of ethanol (ethyl alcohol). For metallography steps, a concentration of 2% nitric acid is usually used. This reagent is recommended to expose low and medium carbon structures when there must be a sharp contrast between perlite, cementite and ferrite [11].

Thus, a chemical attack was performed by immersing the specimen surface embedded in bakelite using the reagents (Nital 2%–2 ml $\text{HNO}_3$ and 98 ml of ethyl alcohol) for approximately 15 s time, whose action was interrupted by running water and cold blast drying. A qualitative evaluation of the specimen surface was performed by bright field microscopy at 500 to $1000 \times$ magnification so as to quantitatively and qualitatively characterize and analyze steel microstructure and correlate with mechanical properties.

Afterwards, specimens were photographed by electron microscopy according to their identification as dual-phase steel grade (DP600 and DP800) by the attacked specimen at 500 × and 1000 × magnification. Bending tests images were captured at 0 and 90 longitudinal degrees in order to evaluate modifications after their conformation. Metallographic images were produced at the Imaging Analysis Laboratory for Materials Testing (LAIMAT) in the Department of Materials and Technology—FEG/UNESP.

Images were photographed in a bright environment using a NIKON MODEL EPIPHOT 200 optical microscope coupled to a computer and an AXIO CAM 1CC3 ZEISS digital camera using the AXIO VISIO—ZEISS software.

Prior to the U bending test, it can be seen in figure 1(a) (DP 600) and figure 2 (a) (DP800) both at 1000 × magnification, that grains are rounded. After the bending test, it can be seen in figure 1(b) (DP 600) and figure 2 (b) (DP800), both at $500 \times$ magnification, the grains became elongated. This phenomenon occurs due to work hardening, which is one of the factors that increase material strength. It can also be observed that DP800 steel has higher martensite content, which is revealed by its dark or black color, consequently it has higher hardness than
DP600 steel. A light or white color represents ferrite which is responsible for material ductility. The content of each phase has been quantified by the Image J software. For DP600 steel, it was found ferrite content of 69.77%, martensite content of 30.23% and standard deviation of 2. For DP800 steel, it was found content of 49.78% for ferrite, 50.22% for martensite and standard deviation of 1.

2.2. Mechanical tests
The mechanical tests performed herein were: tensile test, bending test and Vickers microhardness test.

2.2.1. Tensile test
It was used the tensile testing machine Kratos, model 1KCL3-USB, made available by FATEC—Faculty of Technology, Pindamonhangaba. The size of the specimens can be seen in the figure 3, according to ASTM E8/E8M-13.

For each dual-phase steel grade (DP600 and DP800), the steel sheet was sectioned at rolling angles (0 and 90 degrees). For each rolling angle (0 or 90 degrees), an internal bending angle (30 degrees) was tested. For each internal bending angle (30 degrees), punching rate (4 mm min⁻¹) was selected. For such a purpose, at least 4 replicates were required for each punching rate. The springback effect was observed for 5 days for each punching rate.

To estimate total specimen size for conducting the tests, Minitab 19 was used for estimating sample size through Poisson probability distribution at 95% confidence level with two-sided confidence interval and margin of error of 1.5. The calculated result, according to the adopted method, estimated 72 specimens for the bending test.
Figure 2. DP800 (a) before and (b) after bending test.

Figure 3. The size of the specimens, according to ASTM E8/E8M (tensile test).
2.2.2. U bending test
The machine used for the bending test is Kratos, model 1KCL3-USB, i.e. the same used in the tensile test. The distance between supports was 14 mm according to the ASTM E290 standard. Initial internal bending angles were measured by a magnetic digital inclinometer coupled to the specimen edge and, as the sheet descends along the vertical axis, the digital inclinometer (figure 4) adjusted the internal bending angle until it reached 30 degrees. When the specimen was automatically lifted from the machine, the internal bending angle was again measured by a professional ruler after 20 s and the springback effect was measured in degrees. These measurements continued to be made 5 days afterwards.

2.2.3. Vickers microhardness test
Vickers microhardness tests were performed after the bending test. It was found that there has been an increase in hardness for both steel grades. The structure of metals is modified by plastic deformation due to the application of force on the specimen during the bending test, thus their mechanical properties are improved, such as strength and hardness. This phenomenon is called work hardening which basically occurs due to the fact that metals deform plastically through dislocation mobility, which in turn interact with each other and with other imperfections. Consequently, there is a reduction in disagreement mobility that requires force majeure for plastic deformation to occur. The bending region where work hardening occurred showed the highest Vickers microhardness values, as it can be seen in figure 5 (DP600 steel) and figure 6 (DP800 steel). It is also observed that hardness varies according to rolling angle. For both DP600 and DP800 steel grades, Vickers microhardness was higher at 90 degrees with respect to the rolling angle. This is due to anisotropy which will be analyzed in the following sections.

3. Results and discussions
The mechanical properties of steel sheets change according to rolling angle, otherwise known as anisotropy. It also occurs due to the conformation process in which metal grains are in different particular directions after mechanical strain through the application of force.

According to the author Dieter, G E, 1981 [8] the anisotropy index R can be calculated by the length-to-width ratio of strain while performing the tensile test of a standard specimen before and after the test. After conformation, the value of R can be calculated by equation (1):

\[
R = \frac{e_w}{e_t} = \frac{\ln \frac{y}{y_0}}{\ln \frac{t}{t_0}}
\]
where $W_o$ and $W_f$ are initial and final widths, respectively, and $t_o$ and $t_f$ are initial and final thicknesses, respectively.

To calculate the anisotropy index, the specimen was sectioned at various rolling angles: 0, 45 and 90 degrees. From these tests, values of $R_0$, $R_{45}$ and $R_{90}$ are disregarded. The value of $R$ is called normal or average anisotropy and is given by equation (2) and $R$ variation within the sheet surface is called planar anisotropy, given by equation (3).

$$
\bar{R} = \frac{R_o + R_{90} + R_{45}}{4}
$$

(2)
According to the tensile test for both DP600 and DP800 steel grades, normal or average anisotropy ratio was $R_{45} > R_{0} > R_{90}$. Normal anisotropy ($R$) values obtained in thickness and width measurements of specimens before and after the tensile test were less than 1, but close to 1 (table 1). Since planar anisotropy ($\Delta R$) values were very low, it provides greater strength with respect to sheet thinning. It can also be noted that $R_{DP600} > R_{DP800}$, as DP600 has better formability if compared to DP800.

The tensile test was conducted according to the ASTM E8/E8M-13 standard and specimens were sectioned by Computational Numerical Control (CNC) at 0, 45 and 90 rolling angles using a Kratos, model 1KCL3- USB. The results of stress x strain graphs reveal that the mechanical properties are different by varying the rolling angle, as it can be seen in figure 7 and table 2.

It can be observed that for DP600 and DP800 dual-phase steel grades, there was a difference in yield stress values as regards rolling angle, as it can be seen in table 2 in decreasing order, $\sigma_{DP600} > \sigma_{DP800}$. The order of values with respect to rolling angles for total strain was reversed when compared to the order of values concerning rolling angles for yield stress, $\varepsilon_{DP600} > \varepsilon_{DP800}$. Once dual-phase steel grades are improved (DP 600 to DP 800), the mechanical properties of mechanical strength are enhanced, i.e. yield strength ($\sigma_{DP800} > \sigma_{DP600}$) and tensile strength ($\sigma_{DP800} > \sigma_{DP600}$), however, strain values resulted in reverse order ($\varepsilon_{DP800} > \varepsilon_{DP600}$), as expected.

In figure 8, by comparing the DP600 and DP800 steel grades and keeping other parameters and rolling angles constant, it can be observed that for the same punching rate (4 mm min$^{-1}$) and internal bending angle

### Table 1. Normal anisotropy ($R$) and planar anisotropy ($\Delta R$) values.

|        | $R_0$ | $R_{45}$ | $R_{90}$ | $R$ | $\Delta R$ |
|--------|-------|----------|----------|-----|------------|
| DP 600 | 0.98  | 1.05     | 0.899    | 0.996 | −0.117     |
| DP 800 | 0.955 | 0.978    | 0.897    | 0.946 | −0.017     |

### Table 2. Mechanical properties (DP600 and DP800).

|        | 0 SL | 45 SL | 90 SL |
|--------|------|-------|-------|
|        | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |
| DP 600 | A | 662 | 1 | 665 | 2 | 666 | 2 |
|        | B | 22 | 1 | 22 | 1 | 20 | 1 |
|        | C | 395 | 4 | 388 | 2 | 425 | 4 |
| DP 800 | A | 925 | 2 | 920 | 2 | 925 | 3 |
|        | B | 18 | 1 | 18 | 1 | 16 | 1 |
|        | C | 450 | 3 | 440 | 5 | 482 | 3 |

Where $\mu = \text{mean}$, $\sigma = \text{standard deviation}$, $A = \text{tensile strength (MPa)}$, $B = \text{total strain (\%)}$ and $C = \text{yield stress (MPa)}$.

$$R = \frac{R_0 + R_{90} - 2R_{45}}{2}$$ (3)
(30 degrees), DP800 steel has obtained higher springback value. This steel is known to have a higher martensite content, which hinders its formability. Once steel grades are kept constant according to figure 9 (DP600 steel) and figure 10 (DP800 steel), both at punching rate of 4 mm min⁻¹, it can be concluded that steel at rolling angle of 90 degrees obtained higher springback values, as they presented higher yield stress, thus higher martensite content.

It is also observed that shortly after the bending test, while observing springback variation during the following five days and using the statistical assumptions by the ANOVA and Tukey’s range test, it can be concluded that there is a significant difference in the springback effect during the following days of observation, i.e. it continues increasing until stabilization occurs. The largest increase occurs during the first measurement, i.e. 20 s after the bending test (represented from day 1).
4. Conclusion

Anisotropy and steel grade variation (DP600 and DP800) are the factors that most influenced the springback effect. In addition, rolling angle, internal bending angle, punching speed and steel grade were the variables changed the springback effect value most. However, when comparing these variables, there is a less dramatic change in observation time. The springback value calculated for Dual-Phase DP600 and DP800 steel sheets was higher at a rolling angle of 90 degrees. Although planar anisotropy is negative, the value is very low. A $\Delta R$ of zero indicates that the material has an isotropic behavior. It is interesting to incorporate operations that are to or close to zero as this will allow uniform deformation without the formation of ears in a printed product. The $\Delta R$ of planar anisotropy is directly related to the height of the ears. Normally, for $\Delta R > 0$, the ears occur at $0^\circ$ and $90^\circ$, being characteristic of low carbon steels, while for $\Delta R < 0$, the ears occur at $45^\circ$ and $135^\circ$ compared to the characteristic of low carbon steels and higher resistance (higher LE) [3, 9]. If earing defects occur, it will be at a rolling angle of 45 degrees. Normal anisotropy index resulted in $R < 0$, but it was very close to 1, thus the steel sheet can behave as an isotropic steel sheet, without the formation of earing defects. In the bending tests performed in this study, no ear defects were identified, but nothing can be said about conformations involving larger areas. It is necessary to find solutions for the production of isotropic sheets so as to avoid manufacturing defects, such as ear defects ($\Delta R < 0$), without compromising mechanical strength.

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