A Comparison between Dual Phase Steel and Interstitial Free Steel Due To the Springback Effect

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ABSTRACT. This is a study of the springback effect on two kinds of high strength steel, which are: dualphase and interstitial free, currently used as feedstock in the production of vehicles. The mechanical characterization of the springback effect was performed by means of a mechanical conformation test, called three-point air bending, performed by adapting it to the unconstrained cylindrical bending test. It was also evaluated the mechanical properties of the material defined by the tensile test in order to determine its tensile strength, yield strength, and elongation. Furthermore, it was performed a microstructural characterization of advanced steels by identifying and quantifying the present phases in coexistence by means of digital image processing. The results indicate that the springback effect in the dual-phase steel has the highest springback rates due to its high mechanical strength, and it causes a decrease in the aspect ratio of the grains that suffered mechanical conformation attempting to return it to its original form. On the other hand, the springback effect has the lowest rates, and the change in aspect ratio depends only on the interstitial free steel elongation capacity due to its lower mechanical strength.

1. Introduction. From the 1950's, there was a concern of the automotive industry to produce steel with high formability and low price, and this influenced in changes in vehicle models. In the 1970's, due to the oil crisis, many countries took serious measures to reduce and rationalize energy consumption. The automobile industry then had to find solutions, bringing developments in aerodynamics and reducing vehicles weight. In addition, in all countries, there can be no growth in the automotive sector without giving due importance to the steel mills [1].

The automobile industry has taken steps such as reducing the size of vehicles, replacement of materials, which are traditionally used for aluminum and plastic, and replacement of carbon steels. As a result, steelmakers aimed primarily to promote the assembly of advanced materials with high strength, ensuring an increased structural integrity, an increased resistance to shock, with a lower cost to the final product [2].

A system sets the conventional high-strength steel (HSS) as those having yield strength between 210 and 550 MPa and tensile strength between 270 and 700 MPa, while the high strength advanced steel (AHSS) has a yield strength that is greater than 550 MPa, and tensile strength greater than 700 MPa [3].

The main difference between the HSS and the AHSS is their microstructure. HSS steels are ferritic-pearlitic, of a single phase. AHSS are steels which mainly contain a microstructure with a different phase than ferrite, for example, martensite, bainite, austenite and/or retained austenite in sufficient quantities to produce their own mechanical properties. However, the widespread use of AHSS in the automotive industry is limited due to challenges in formability, metal sheet, tool life, and to the springback effect. It is a major problem that compromises the mass production of automotive structural components with AHSS [4].

According Ramezani [5], it is a partially undesirable change occurring in steel sheets as a result of the constraints removal after their conformation process. The two types of steels studied in this work are among the major steels used by automobile industries nowadays because they are high strength steels, being dual-phase steel (DP), which is an AHSS, and interstitial free steel (IF), which is a HSS.

2. Experimental procedure.

2.1. Metallography before the conformation. The following metallographic preparation processes are standardized by ASTM ID: E 3-10 (2007). Test specimens were made from DP and IF steels as delivered at the dimensions of 10 mm long, 10 mm wide, 0.8 mm thick.

After sectioning in the longitudinal direction of rolling, the specimens were subjected to hot embedding with bakelite. During the grinding, the following abrasives were used: 220, 320, 400, 600, 1000, and 1200 mesh. The polishing was performed in an OP-U solution and distilled water, subjecting the specimens to a rotation of 600 rpm. The chemical etching was done with a 2% Nital solution to reveal the grain boundaries of ferrite and constituents [6].

The micrographs were obtained using the NIKON optical microscope, model EPIPHOT 200. The image processing was done using the Image J 1.45 software. All images were standardized in the same luminosity conditions and gray shades scale with the use of tools to enhance contrast, normalize and equalize histogram.

2.2. Mechanical conformation tests. Test specimens were made from the same material as delivered and sectioned at the following dimensions: 80 mm long, 30 mm wide, and 0.8 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 [7].

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

The punch had a 5 mm radius and the distance between the supports of the die was 13 mm, according to the ASTM ID: E 290-09 standards to a sample thickness of about 1 mm. The three-point air bending was performed in a universal Shimadzu testing machine, 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 new bend angle measurement was made to determine whether there was a springback effect or not. For this measurement, it was used the Image J 1.45 software for processing images photographed on an Olympus digital camera. Such measurements continue to be made for a period of 12 h, 24 h, 48 h and 72 h after conformation. Completed the 72 h after the mechanical bending, the resulting bending angle was subtracted from the initial angle of bending which were of 30°, 60°, 90° or 120°, respectively, and this subtraction resulted in a total springback angle ($\theta 1 + \theta 2$), as shown in Figure 1.

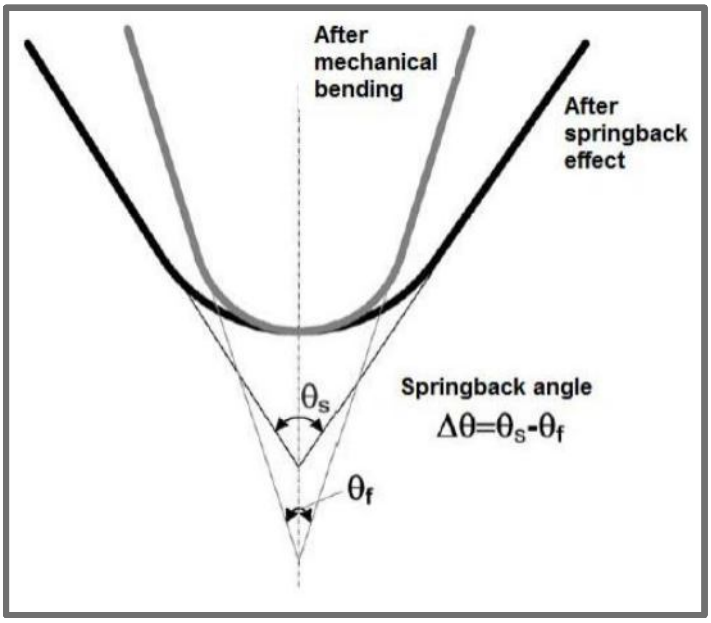

Fig. 1. Definition of springback angle [8].

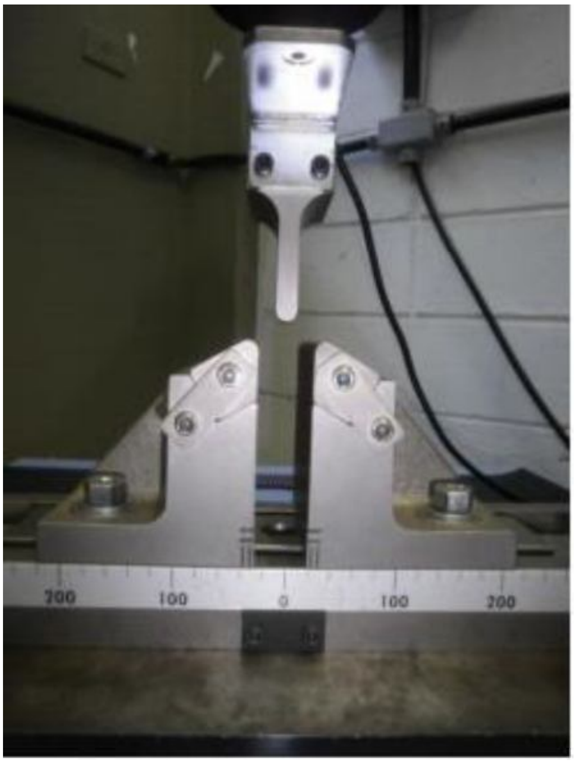

Fig. 2. Device mounted universal testing machine for testing three-point bending in air.

2.3. Metallography after the conformation. Test specimens were made from materials that were subjected to a mechanical bending test after 72 hours of evaluation at the following dimensions: 10 mm length x 10 mm wide x 0.8 mm thick. The region of the steel plates chosen to obtain the specimens was the one where a curvature was formed due to bending. The specimens were cut in a longitudinal direction, i.e., in the direction of the steel plates lamination by dividing them in the middle. This material was embedded in order to expose its inner surface in order to obtain samples of the region that was deformed during the bending.

The metallographic followed in the same manner as in the pre-conformation test, with the use of hot embedding and polishing, and the chemical etching was made with a 2% Nital solution. The 30 analyzed pictures were for each treatment.

3. Results and discussion.

With respect to the mechanical properties, shown in Table 1, they were obtained by tensile tests, extracting the specimens in a transverse direction at 45°, and in the rolling direction of the material. In table I, the tensile strength was designed by RT in MPa, yield strength by LE in MPa, and elongation by Elong in %.

Table 1. Mechanical properties of materials dual-phase steel (DP) and interstitial free steel (IF)

Material	RT (MPa)	LE (MPa)	Along (%)
DP	623.6 ± 2.9	407.3 ± 3.6	23.4 ± 1.4
IF	298.0 ± 2.1	147.9 ± 3.8	40.9 ± 1.9

As shown in Figure 3, the dual-phase steel showed the greatest springback angle (between 7 and 9 degrees), and the interstitial free steel had lower angles (between 4.5 and 6 degrees).

Thus, Figure 3 shows the results that can be compared with W.Gan's 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 [9].

Moreover, as shown in Figure 2, the angular variation of the springback effect was increased from 120° to 30°. This means that as the extent of the internal angle bending was being reduced from 120°, 90°,60° to 30°, an increase in the springback effect occurred.

According to the dual-phase steel, a decrease in the internal angle bending causes a greater springback effect.

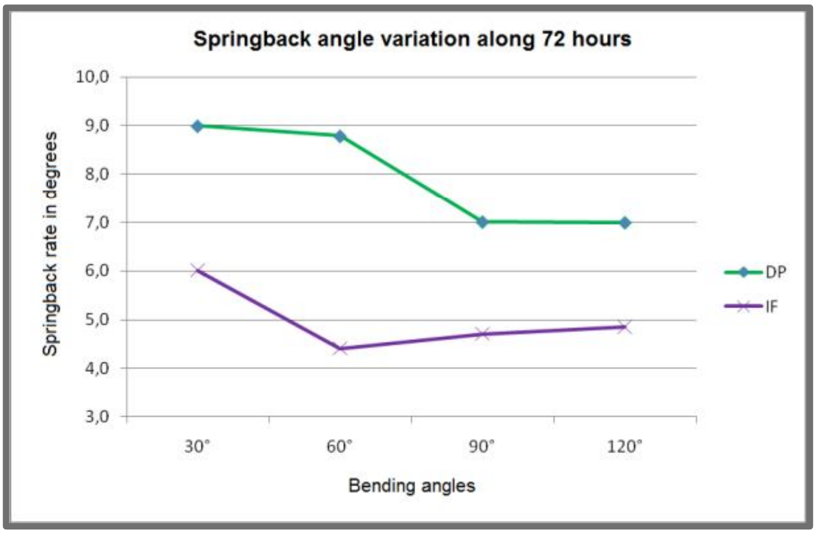

Fig. 3. Angle variation of the springback effect for different bending angles after 72 hours

The ANOVA was used as a statistical tool for interpreting the results. It means a variance analysis, and it is a test of treatment average comparison. It was used a two-factor ANOVA type with repetition, submitted to an F test, at a significance level of 5%.

According to Table II, the time and degree factors significantly influenced the results of springback effect in the dual-phase steel. It can be verified that, according to F Test, - p value was lower than 0.05 which were different from each other in average. The same is not true for the interactions where the – p value is greater than 0.05, indicating that the treatment time and degree did not cause interactions together with the results.

Table 2. Analysis of variance of springback effect to dual-phase steel

Source of variation	***SQ***	***gl***	***MQ***	***F***	***Value-P***	***F-critic***
Time	9.487148	4	2.371787	3.188721	0.023015831	2.605975
Degree	59. 80007	3	19.93336	26.79916	1.14078E-09	2.838745
Interactions	1.196571	12	0.099714	0.13406	0.999686828	2.003459
Inside	29. 75221	40	0.743805			
Total	100.236	59				

Examining Table III, where an analysis of variance for the aspect ratio is shown, - p value is less than 0.05, thus the variation in the aspect ratio for the dual-phase steel differentiates along the treatment degrees at a significance level of 5%.

Table 3. Analysis of variance of the aspect ratio after 72 hours of the springback effect, considering the four internal angles of bending applied to the dual-phase steel from 30 photos

ANOVA						
Source of variation	***SQ***	***gl***	***MQ***	***F***	***Value-P***	***F-critic***
Among groups	0.03813	4	0.009533	2.631578	0.036708	2.434065
Within groups	0.525241	145	0.003622			
Total	0.563372	149				

An analysis of variance for the interstitial free steel subjected to the springback effect is shown in Table IV which indicates that the difference between the means were significant only for the factor degree, and this is the only one where the - p value is less than 0.05. The time factor and the interactions between time and degree did not have an influence on the springback effect.

Table 4. Analysis of variance of springback effect to interstitial free steel.

Source of variation	***SQ***	***gl***	***MQ***	***F***	***Value-P***	***F-critic***
Time	3.204853	4	0.801213	0.535429	0.710460251	2.605975
Degree	24.25645	3	8.085484	5.403309	0.003232364	2.838745
Interactions	0.260574	12	0.021714	0.014511	0.999999999	2.003459
Inside	59.8558	40	1.496395			
Total	87.57768	59				

Table 5 has an analysis of variance to evaluate the influence of the springback effect in the aspect ratio. It was concluded that this effect caused a significant change in aspect ratio, since the - p value was less than 0.05.

Table 5. Analysis of variance of the aspect ratio after 72 hours of the springback effect, considering the four internal angles of bending applied to the interstitial free steel from 30 photos.

ANOVA						
Source of variation	***SQ***	***gl***	***MQ***	***F***	***Value-P***	***F-critic***
Among groups	3.56368	4	0.89092	2.551933382	0.041591	2.434065
Within groups	50.62177	145	0.349116			
Total	54.18545	149				

As shown in Figure 4, the aspect ratio for the 180° angle refers to the material as delivered before suffering mechanical bending. In this graph, it is seen that the treatment is the most different from the others which was at 120°, thus obtaining a greater aspect ratio. As for the other treatments, the aspect ratio values are closer to the material as delivered.

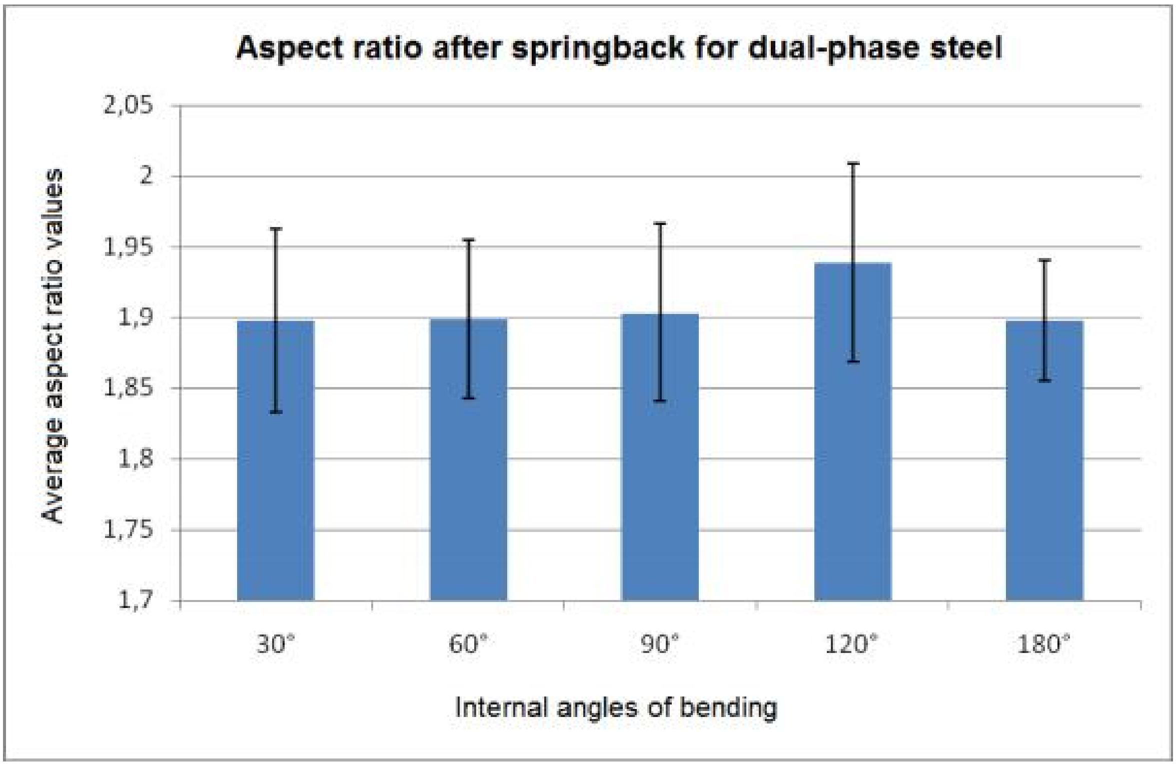

Fig. 4. Average aspect ratio values and their standard deviation of vertical bars 72 hours after removal of constraints obtained from 30 pictures for each internal angle of bend of 30° to 120°, and 180° to material as received.

To view the mechanical influence of the springback effect on the conformation and aspect ratio, it is mounted the graph of Figure 5 from which it is observed that the treatment at 30° was the only one that had the highest mean values of the aspect ratio.

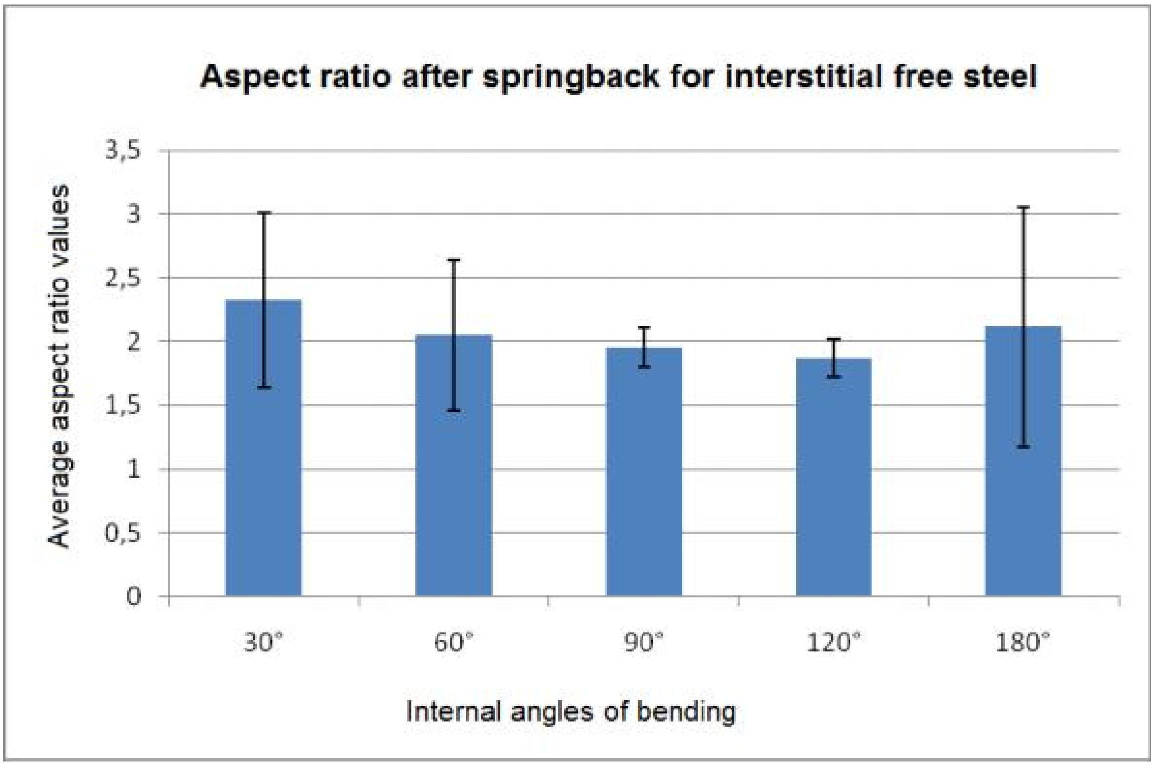

Fig. 5. Average aspect ratio values and their standard deviation of vertical bars 72 hours after removal of constraints obtained from 30 pictures for each internal angle of bend of 30° to 120°, and 180° to material as received.

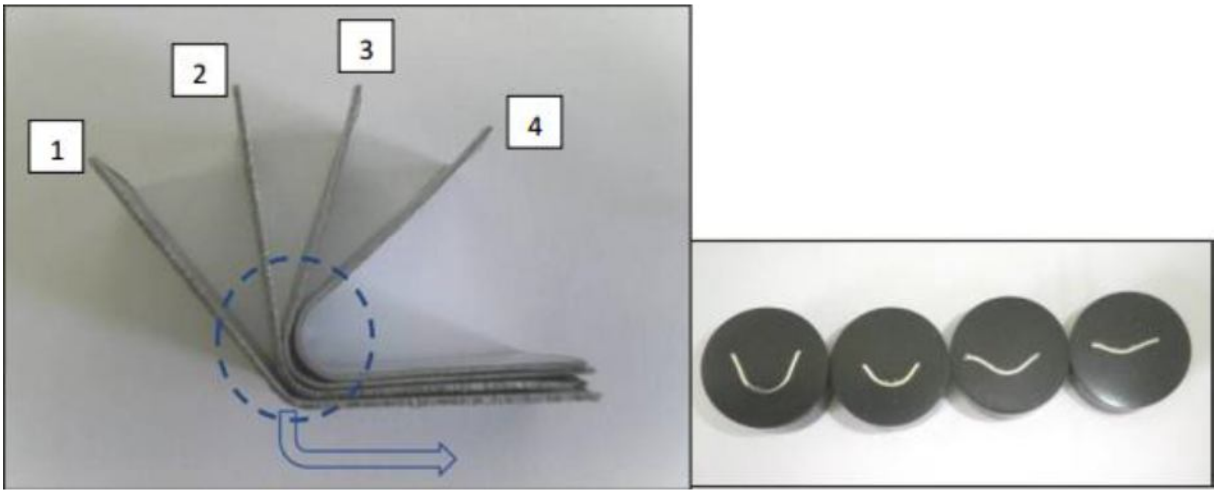

Fig. 6. Samples of sheets, for illustration, already subject to three-point bending in air and subsequent springback effect for 72 hours, where the numbers refer to the values of angles of bending applied, with (1) was 120°, (2) was 90° (3) was 60° and (4) was 30° and the region conformed subjected to the mounting respectively of 30° to 120°.

Figure 7 from (a) to (d) are images of the dual-phase steel microstructure obtained by an optical microscopy. It is observed the presence of martensite microstructure (dark portion) in all images, like islands immersed in the matrix of ferrite (light portion). Images (c) and (d) differ from each other because it is observed the presence of more elongated ferrite grains in its transverse direction. Thus, the material subjected to the treatment at 120° presented the highest aspect ratio.

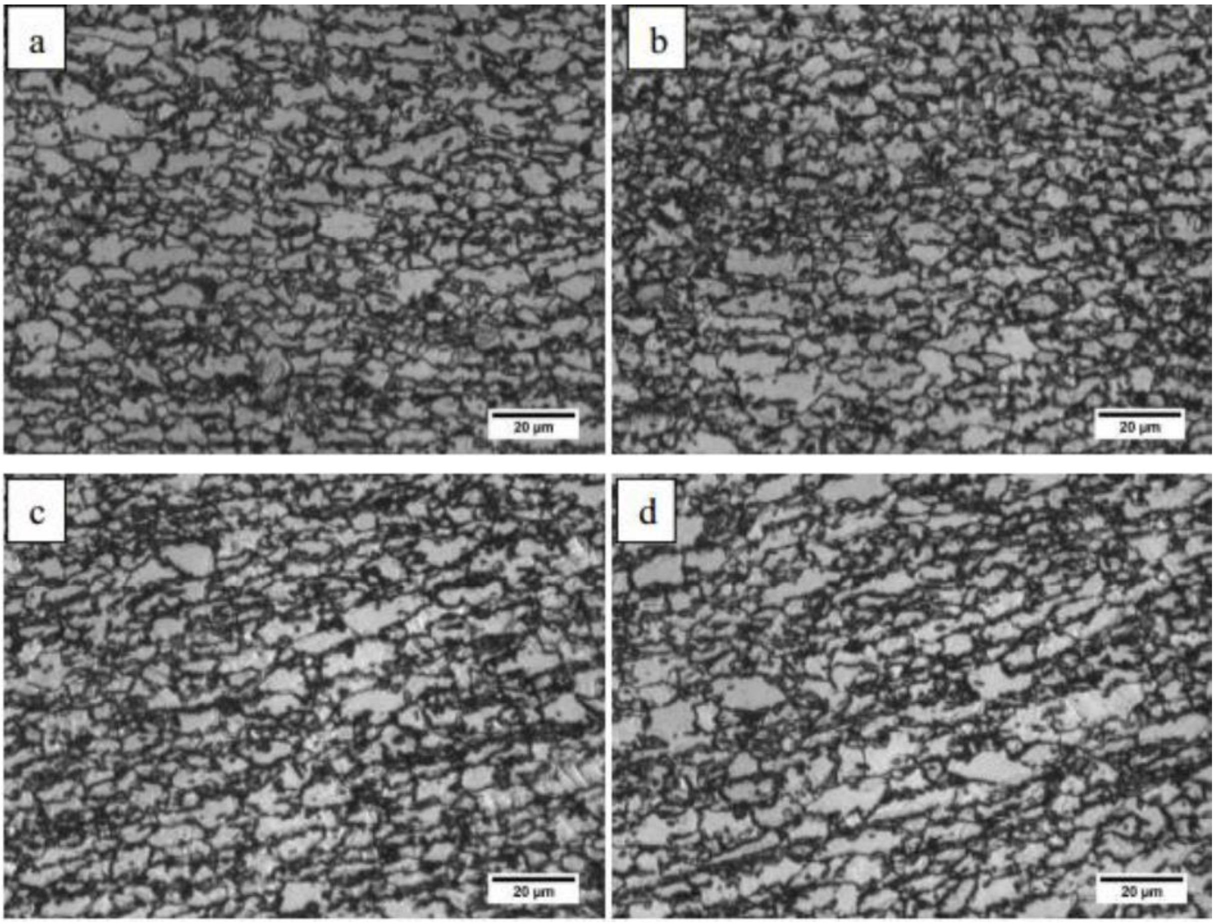

Fig. 7. Optical microscopy images dual-phase steel as received and subjected to mechanical bending, where (a) and (b): material as received; (c) and (d): 120°, increase of 500X, reagent Nital 2%.

In Figure 8 from (a) to (d), which are images of the microstructure of the interstitial free steel, is noted the presence of ferrite microstructure. Images (c) and (d) show more elongated ferrite grains in one direction. These grains have also to be flatter when compared to the images above, and the images obtained from the treatment at 30° have the highest aspect ratio.

An evidence that the variation in the aspect ratio is influenced by the springback effect and not only by the elongation rate of the steel that can be obtained by analyzing the dual-phase steel which presents the lowest elongation rate among the two materials. Thus, if the aspect ratio were influenced only by the elongation rate, all other treatments of bending for this steel would have aspect ratios which are statistically identical to the material as delivered.

However, for the treatment at 120°, its aspect ratio was statistically higher than that of the material as delivered, since this treatment was the one that had the lowest springback effect which was not sufficient to negate the effects of conformation. In all bending treatments, the dual-phase steel lengthened, but the high springback effect of treatments at 90°, 60° and 30° were sufficient to return the grains to their original shapes, resulting in the similar aspect ratios of the material as delivered.

Therefore, in the dual-phase steel, the aspect ratio variation is independent on the elongation rate of the grains because a severe reduction of the internal bending angle causes a high aspect ratio for the mechanical conformation. This aspect ratio decreases after the springback effect, and it increases with a decrease in the internal bending angle due to high yield strength.

By establishing a relationship between the microstructure and the springback effect for the interstitial free steel, it is possible to say that the greatest springback effect occurred in the treatment at 30°, and this treatment had the highest average aspect ratio in its individual grains.

Therefore, it is possible to observe that in the interstitial free steel, the springback effect did not cause a decrease in the grain aspect ratio, as with the dual-phase steel.

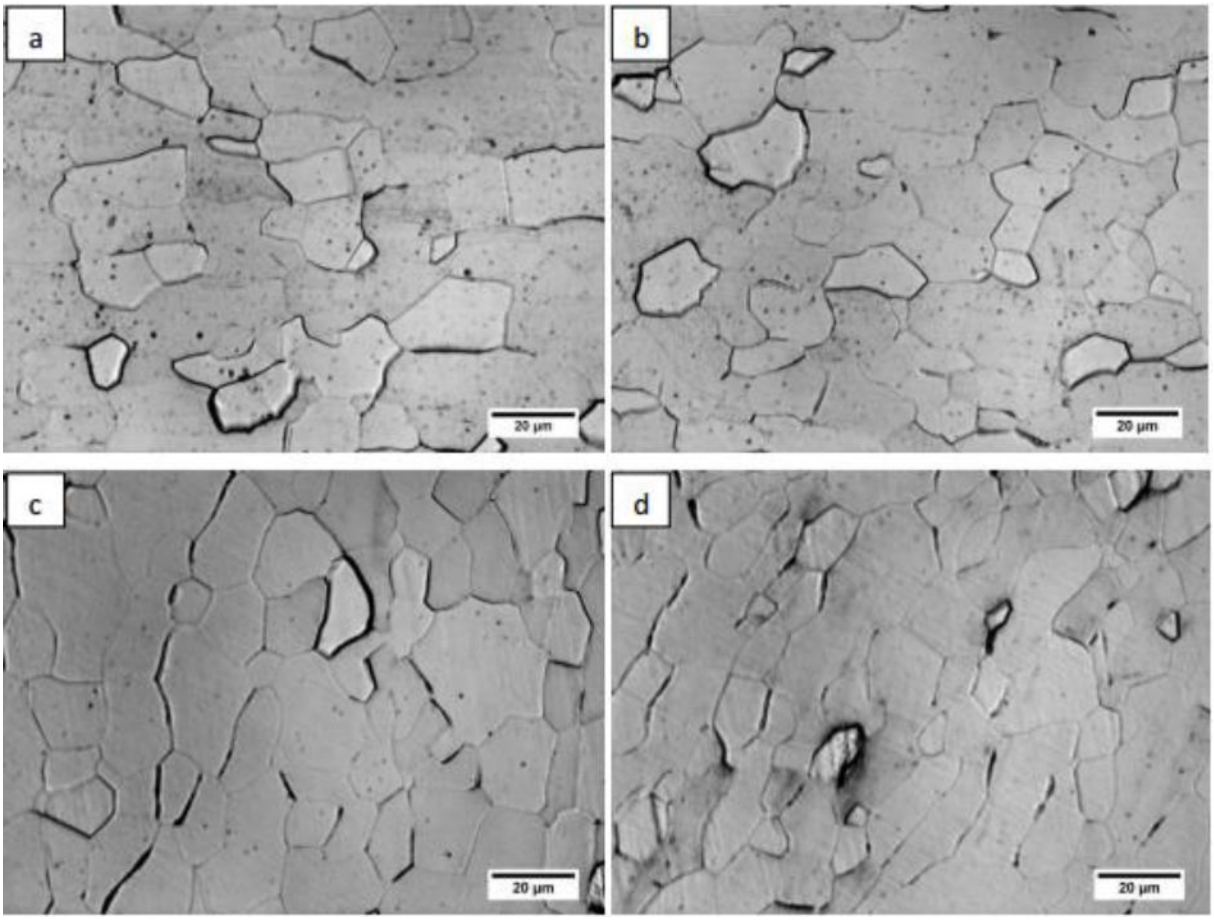

Fig. 8. Optical microscopy images interstitial free steel as received and subjected to mechanical bending, where (a) and (b): material as received; (c) and (d): 30°, increase of 500X, reagent Nital 2%.

The interstitial free steel has the lowest limits of yield strength and tensile strength compared to the aforementioned steel. Moreover, it has an elongation rate of 17% which is higher than with the dual-phase steel. Because of a lower mechanical strength of the interstitial free steel in comparison to the previous steel, only during the application of the treatment at 30° which is the acutest internal angle resulted in a significantly different amount of springback effect from the other treatments.

The interstitial free steel is less resistant from the previous one. Its springback effect is less evident, and it can be said that its grains have a lower need for stress relief after the bending when compared with the most resistant steel, and its grains begin to present a greater need to relieve stress only in the acutest internal angles, causing a greater springback effect.

Summary. It follows that for the dual-phase steel, more springback effect causes a lower aspect ratio of grains, and a lower springback effect causes a greater aspect ratio of grains which shows that it is a high strength steel. And the opposite occurs for the interstitial free steel with which a greater springback effect accompanied by a greater aspect ratio of grains.

In the dual-phase steel, the aspect ratio is directly proportional to the internal angle of bending. An internal angle decrease increases the springback effect which causes a decrease in the aspect ratio. In this steel, the variation in the aspect ratio depends only on the ability of mechanical resistance.

In the case of the interstitial free steel, the variation of the aspect ratio of their grains is inversely proportional to the internal angle of bending. Thus, the decreasing internal angle increases their aspect ratio. Therefore, for this steel, as opposed to dual-phase steel, the variation of aspect ratio depends on its elongation ability.

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