

NUMERICAL SIMULATION OF THE REINFORCEMENT SUSPENSION STAMPING IN INTERSTICIAL-FREE AND DUAL-PHASE STEEL

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Abstract. *The automobilistic industry was hardly reached by the energy crises, what made it look for solutions through aerodynamic evolution, searching alternative consumable and reducing the vehicles weight. With that, the making steel industries aimed, mainly, encourage the automobilistic industries with advanced materials of high resistance, giving guarantee of the structural integrity increase, impact resistance increase, with a smaller cost at the end product*

In the high resistance steel, distinct the dual phase steel (DP), the interstitial-free steel (LI), and the multiphase steel (Pereira, 2004). Within de new concept of fabrication is observed that DP represents 74% of the raw material employed in the automobiles fabrication (ULSAB Overview Report, 1997).

The production of special steels, which is currently about 57 million ton per year, representing about 7,6% of the siderurgical production, have been developing at superior rates comparing to common steel (ANDRADE et al., 1996). The estimate about the production and the global steel consume, are based on the evolution of Automobilistic Industry production, which consumes about 90% of the steel production for mechanical construction. Thus, is considered that, the current consume is about 40 million ton per year of this kind of steel, representing about 6% of the global consume (Andrade et al., 1996).

The objective of this research was study the conduct of the dual phase steel (DP) and the interstitial-free steel (LI) during the stamping in the fabrication of the reinforcement suspension. Researches about the mechanical testing and about softwares were realized too, to give theorical base about the tests, which would be realized later.

The difficulty about the conformation of the DP steel was checked during the stamping, comparing to LI and dimensional differences in different points. The LI material got closer to the objective in the project.

The drawability of the most resistant steels, makes the width of the products possible and consequently reduces the vehicles weight, reducing the emission of pollutant in the atmosphere, but needs an improvement in the steel and stamping process fabrication to thinner width.

Keywords: *DP steel, LI steel, multiphase steel, stamping.*

1. INTRODUCTION

The Interstitial-free steels (LI) were developed on the last decades as an alternative to improve the formability in plan products for the extra-profound stamping. The carbon and the nitrogen in the LI steel normally are in the condition of carbonates and nitrates of Ti, Nb and Al, depending on the steel kind. The precipitate morphology and the hot-rolling product microstructure are controlled by the hot processing condition, as: reheating temperature, finishing, reduction, pass numbers, rolling speed and rate of cooling. These steels present an extra-profound drawability together with non-aging proprieties, which it has given opportunity to the automotive industry to produce hard conformability parts more easily and with high resistance (Itami et al, 1995). As characteristic the LI steels have excellent mechanical properties with high values of $\overline{R}$ and n, low flow limit and high total stretch.

Having origin in petroleum crises is observed that, until nowadays, no challenge was so critical to some automotive industries as the vehicle weight reduction. This challenge keeps on and some automotive industries have as an objective the vehicle weight reduction in a third or in a half until 2015 (International Iron and Steel Institute, 1995).

Seeking the weight reduction, the automotive industry had to adopt measures as, reducing the vehicle size, substituting the traditional materials by aluminum and plastics and, the substitution of common carbon-steels. Nevertheless, it can be verified that, the steel is the predominant material at the automotive industry, making about 70% of all the raw material used in a vehicle (Kishida, 2000), detaching the dual-phase (DP) and the multiphase steel (Pereira, 2004).

The dual-phase steel is characterized by harmonizing, in an optimized manner, resistance and conformability. Obtained through intercritical heat treatments, gives the strong characteristic of aligning high resistance, ductility and conformability. This ductility provides from its microstructure, which associates extremely hard phases (martensite and bainite) scattered in a ferritic matrix. This characteristic assures a good drawability, guaranteeing properties equally present on its own parts, more elevated than the plates (in particular the elasticity limit). Its excellent capacity to support fatigue and its high mechanical resistance makes it interesting for the parts of fabrication structure and reinforcement.

The stamping in the automotive industry is substituting casting, forging and machined parts by materials which its behavior seeks allying resistance and conformability. In this stamping process, the numerical simulation in development is still being used in large scale, what requires the mechanical quantification in different stages and deformation in steels, which ally mechanical resistance with conformability. With the simulation is sought too, correlate the simulative tests or the fundamental with the industrially material performance.

By the exposure above, the objective of this research was to study the dual-phase material (DP) behavior and the interstitial-free steels (LI) in laboratory scale and during the stamping process in the production of reinforcement suspension.

2. METHODOLOGY

The materials used on the tests were LI steel plates with 1mm thickness, dual-phase steel, cold-rolled and annealed. The chemical analyses of the plates were made using the plasma emission spectroscopy. Tensile tests were realized according to ASTM E-8M norm, using a servohydraulic machine Instron, with a deformation rate equals to $1s^{-1}$. The anisotropy coefficients were obtained using two extensometers, localized on the transverse and longitudinal directions. The transverse extensometer was responsible for the determination of the deformation on the width direction and the longitudinal, with 25mm of useful length, was used for the determination of the deformation on the length direction of the test specimen. After this deformation, the final length and width were measured. The R, $\overline{R}$ and ΔR calculus were realized through Eq. (2.1), (2.2), (2.3). Having origin on those values, the medium value and the deviation associated to those measures are calculated. The standard deviation was calculated through Eq. (2.4):

$$R = \frac{ln\left(\frac{W_0}{W_f}\right)}{ln\left(\frac{l_0 W_O}{l_f W_f}\right)} \tag{2.1}$$

$$\overline{R} = \frac{\left(R_0 + 2R_{45} + R_{90}\right)}{4} \tag{2.2}$$

$$\Delta R = \frac{\left(R_0 - 2R_{45} + R_{90}\right)}{2} \tag{2.3}$$

$$\overline{S_n} = \sqrt{\frac{\sum\left(x - \overline{x}\right)^2}{n-1}} \tag{2.4}$$

For the calculus of working hardening coefficient, n, was used the conventional deformation of 10% and Nelson and Winlock method (Guimarães Filho, 1990).

$$\frac{P_m}{P_{15\%}} = \left[\frac{1.10}{1+e_m}\right]\left[\frac{n}{ln(1.10)}\right]^n \tag{2.5}$$

where, P_m is the maximum load;

$P_{15\%}$ is the load in 15% of deformation;
e_m is the maximum deformation.

The strength limit was calculated through the Eq. 2.6.

$$\sigma_R = \frac{P_m}{S_o} \tag{2.6}$$

The maximum load value was obtained at the point where the working hardening coefficient assumed the value as zero. The working hardening coefficient was calculated from the data stress *versus* deformation through the Eq. 2.7.

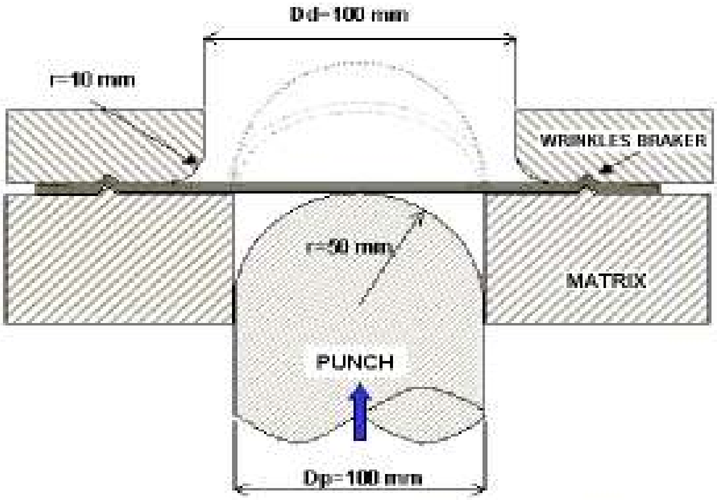
$$\theta = \frac{d\sigma}{d\varepsilon} \tag{2.7}$$

The stretch was calculated through the relation.

$$\Delta l = \frac{l_f - l_0}{l_0} \tag{2.8}$$

where l_f and l_o are, respectively, the final and initial lengths.

The CLCs were obtained according to the proceeding given by Nakajima. The test was realized in a 100tf universal press using a hemispherical punch (Miranda, 2006). Test specimens were selected with the dimensions varying from 180 X 40mm to 180 X 180mm, electroliticaly marked with a squared mesh of 2.5 X 2.5mm. After the conformation, the mesh distortion was analyzed in function of the main deformations ε_1 e ε_2, through the software ASAME (Automated Strain Analysis and Measuremnet Environment), that realizes the deformation measurings in 3 dimensions. The software realizes the comparison of the fracture region with a standard mesh target. Two pictures were taken in different angles, aproximately 45º.



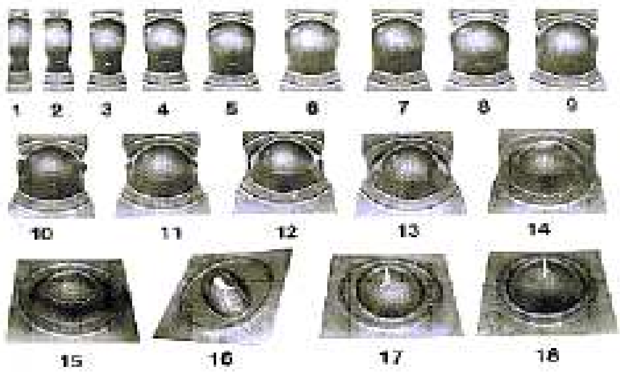


Figure 2.1 – Tool model for the Nakajima method and sequence of the samples used on the determination of forming limit diagram (CLC). Source: William Johny Miranda, 2006.

Those pictures were evaluated by the software through an overposition method in way to obtain a unique mesh in which were realized the maximum and minimum deformations measures (ε_1) and (ε_2). Next, originating from these values the graph ε_1 *versus* ε_2 was obtained. The ASAME calculated 20 dots and these were transferred to an EXCEL plan. A 5th degree polynomial was chosen for the arrangement of these experimental dots and to obtain the forming limit diagram. Originating from CLC curve, the rupture critical area was delimited below in 10% from the CLC curve position.

Two reels were selected and identified, with dimensions of 1 X 1200mm, and sent to Cinafe, where they were pre-processed in a cutting line, Press Blank – PB. The end product is the steel sheet with dimensions 1 X 250 X 1200mm. The packs were sent to Tower Automotive do Brasil – Unit at Betim – for stamping. The presses line was prepared with three dies set in a conjunction base to realize the production, in an 800tf press. The process sequence used for the production is defined to spin on the first operation, to calibrate and trim on the second operation and to punch on the third and last operation. The production analysis was realized considering the productivity, defect ratio (Defect / Production) and the defect characteristic found. The software used to do the stamping simulations was the PAM-STAMP, based on the finite elements.

For the diagrams determination, parts from the first and second spin, with oiling furnished by the maker and from the first spin after cleaning it with alcohol.

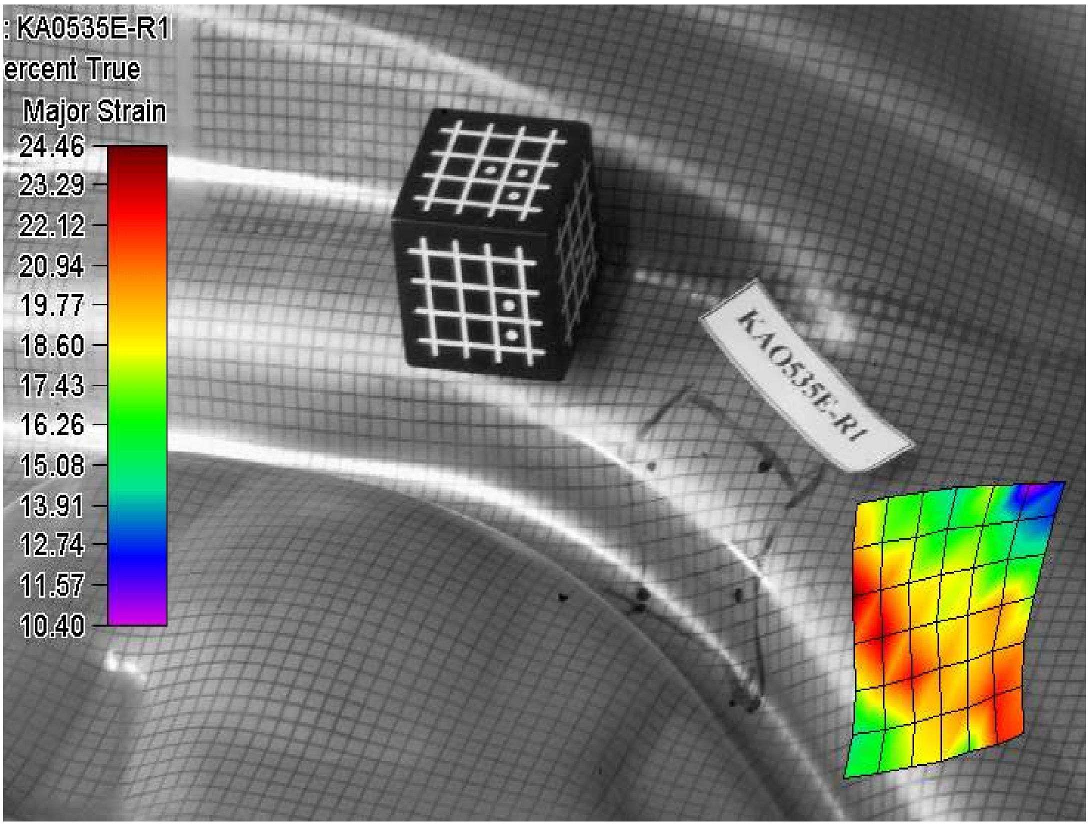


Figure 2.2 – Example of the part picture comparing to the standard target. Source: William Johny Miranda, 2006.

3. RESULTS AND DISCUSSION

The Table 3.1 shows the results from the chemical analyses of the plates with dimensions 1 X 250 X 1200mm, which were used on the research, in percentage in weight.

Table 3.1 –Chemical composition of the plates used on the tests in percentage in weight. Source: Usiminas inspection certificate, SSAB.

Material	C	Mn	P	S	Al	Nb	Ti
DP	0.13	1.50	0.01	0.003	0.036	0.015	0
LI	0.002	0.10	0.01	0.01	0.054	0.002	0.063

Is observed that, the elements Nb and Ti fix the carbon and nitrogen, avoiding, this way, that the LI steel ages after cure.

The presence of Mn at the DP steel increase the hardenability what facilitates the formation of two faces on this steel.

The free-interstitial (LI) micrography presented polygonal ferritic grains with the grain size 8.5 (Fig. 3.1). Otherwise, the dual-phase micrography presented a dual-phase microstructure with martensite presence, at the proportion of 8% (Fig. 3.2).

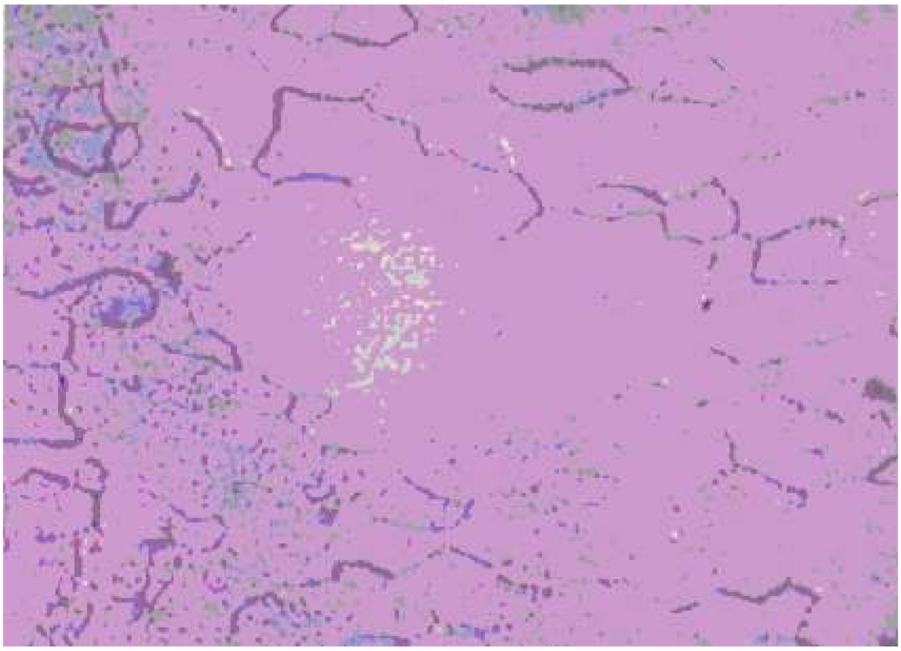


Figure 3.1 – LI steel microstructure obtained in optic microscope. Increase: 400X, attach Nital 3%. Source: Tork – Quality Control of Materials

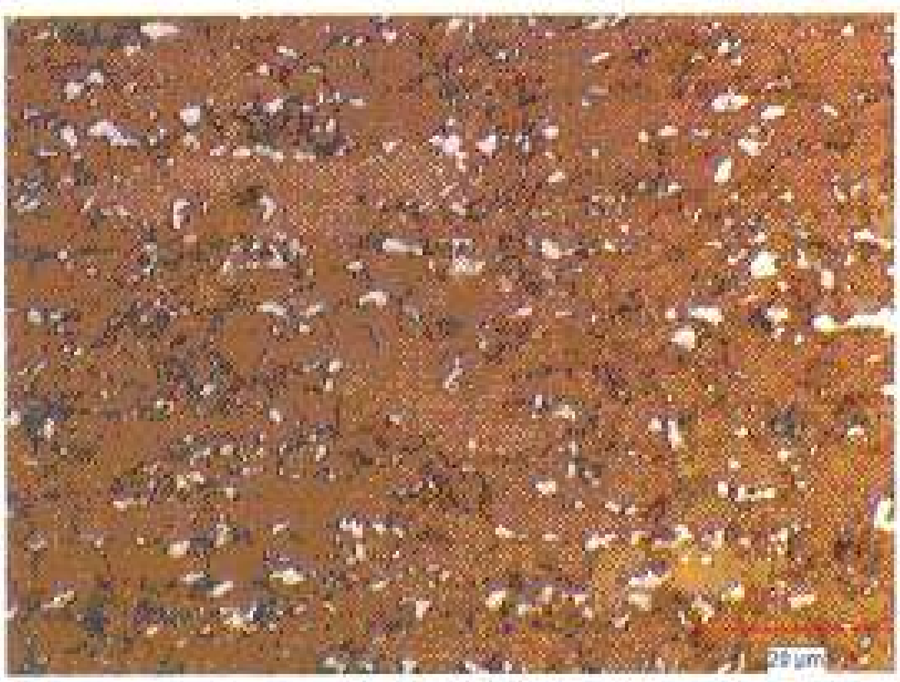


Figure 3.2 – DP steel microstructure formed by martensite (light areas) and ferrite obtained in optic microscope. Increase: 400X, attach Nital 3%. Source: Tork – Quality Control of Materials

The Table 3.2 presents the values for the mechanical properties, yield point (LE), ultimate tensile strength (LR), stretching (AL).

Table 3.2 – DP and LI materials tensile test result. Source: Usiminas inspection certificate, SSAB.

Steel	DP	LI
Yield Point LE (MPa)	375	159
Strength Limit LR (MPa)	649	297
Minimum Stretching AL (%)	26.20	47

The results showed that LI material possesses mechanical properties favorable to the conformability comparing to DP steel, what means, big stretch value and low yield point and strength.

The Figure 3.3 presents the forming limit diagram of the free-interstitial steel (LI).

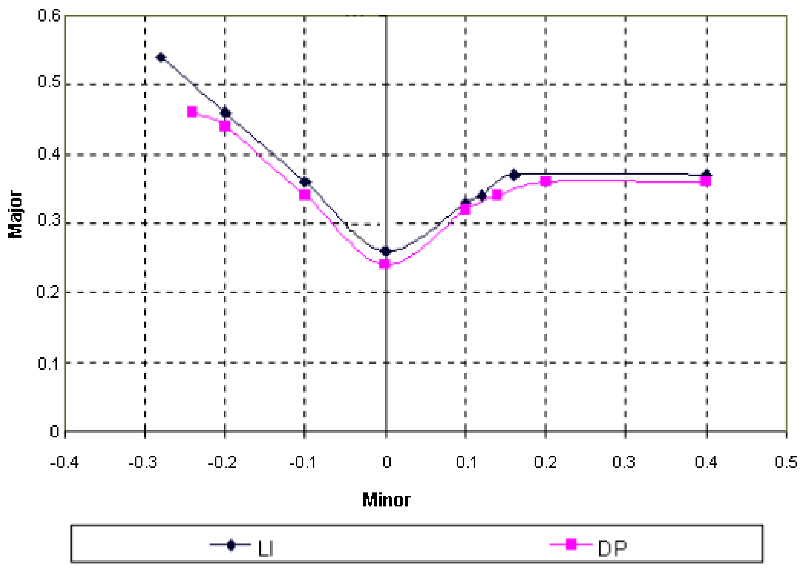


Figure 3.3 – Forming limit diagram of LI and DP steels. Source: Tower Automotive do Brasil laboratory – Unit at Arujá.

Through the diagram of the forming limit diagrams is observed that, the free-interstitial material (LI) has a better conformability than the dual phase material (DP) on the drawing area.

The Figure 3.4 presents the stamping simulation result using the software PAMSTAMP to the free-interstitial (LI) material. Using the scale presented by the software, it becomes conspicuous that the product in analysis won't show drastic thickness reductions, been possible to reach 0.19mm, as seen on the Fig. 3.5.

The Figure 3.5 shows the CLC curve of the LI steel and, simultaneously, the deformations occurred at the part in critical region, evidencing the drawing presence without, however, risk of appearing any fissure.

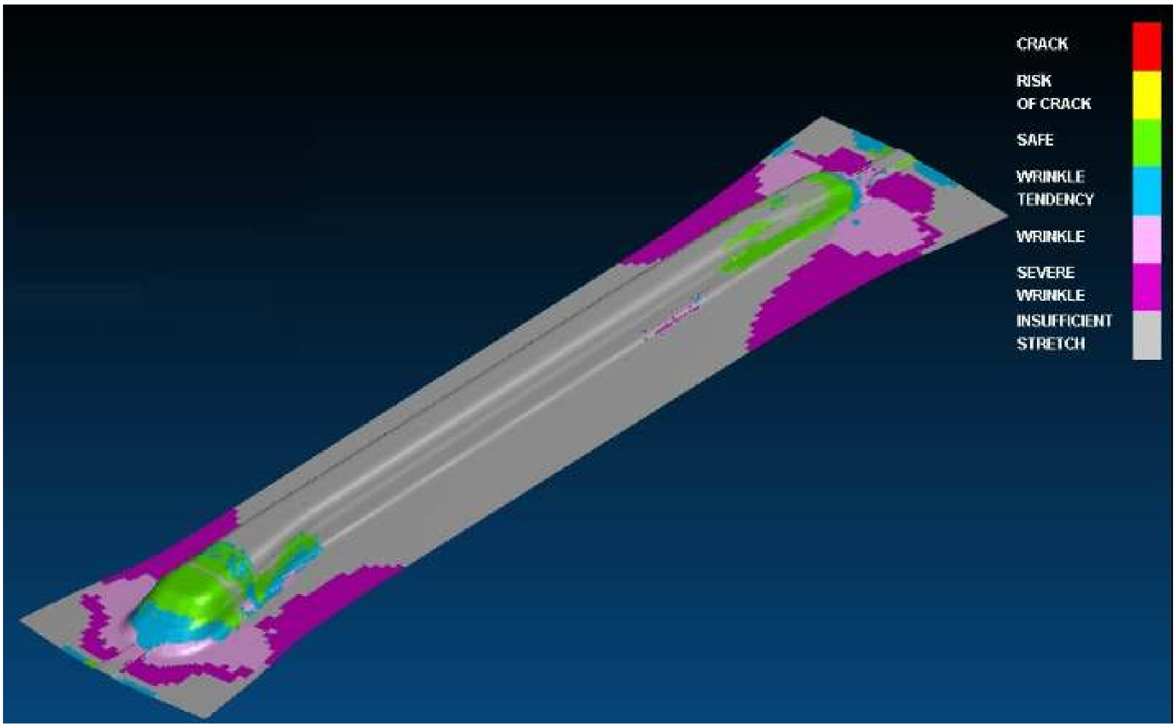


Figure 3.4 – Stamping simulation using LI steel. Source: SEMA Toolroom.

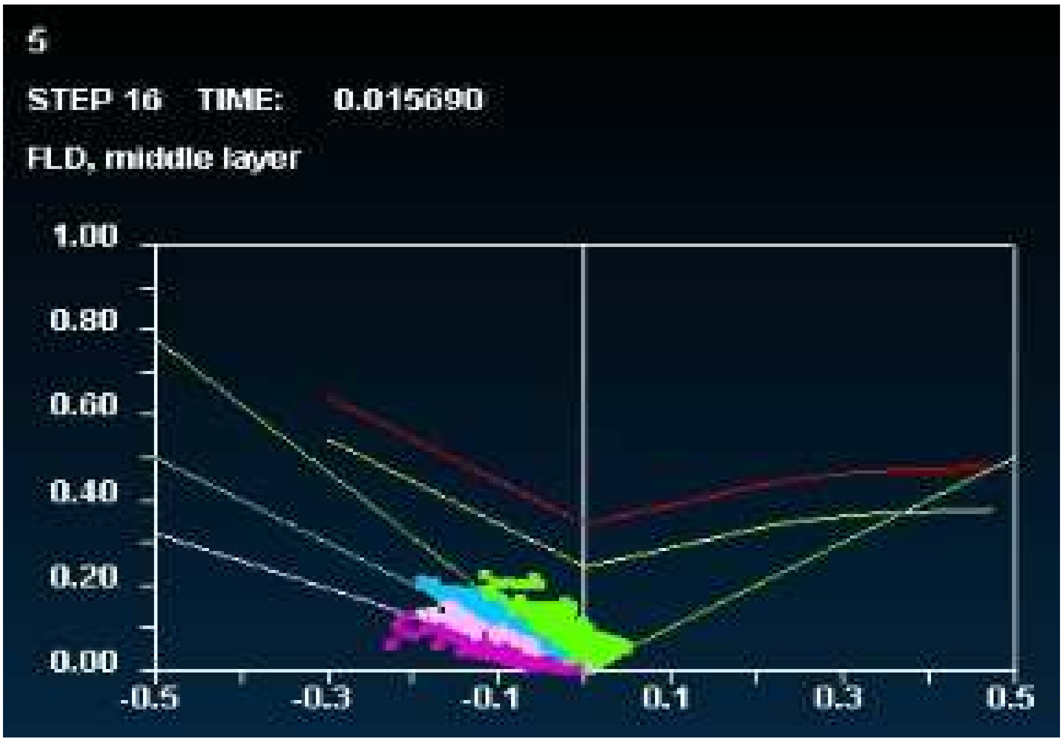


Figure 3.5 – Thickness reduction on stamping simulation using the LI steel. Source: SEMA Toolroom.

The Figure 3.6 presents the stamping simulation result using the software PAMPSTAMP for the dual phase (DP) material. Using the scale presented by the software, it becomes conspicuous that the product in analysis won't show drastic thickness reductions, but been possible to reach at 0.25mm, as seen on the Fig. 3.7

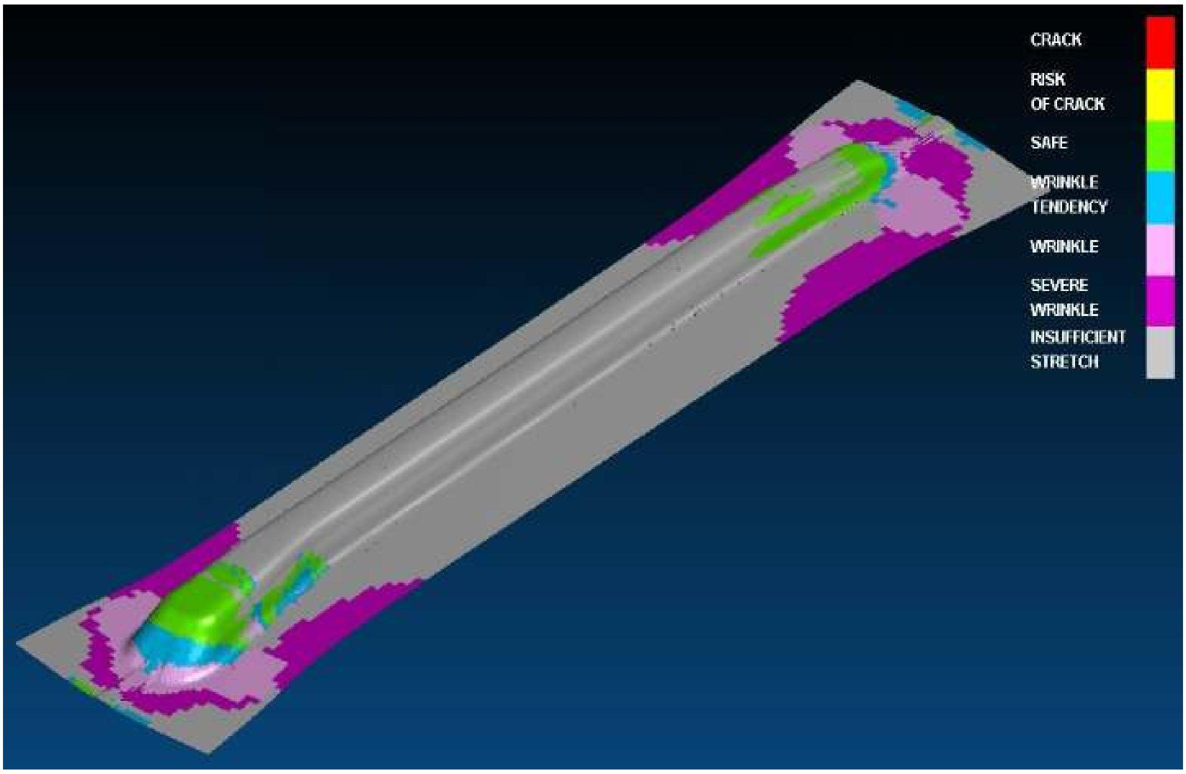


Figure 3.6 – Stamping simulation using DP steel. Source: SEMA Toolroom.

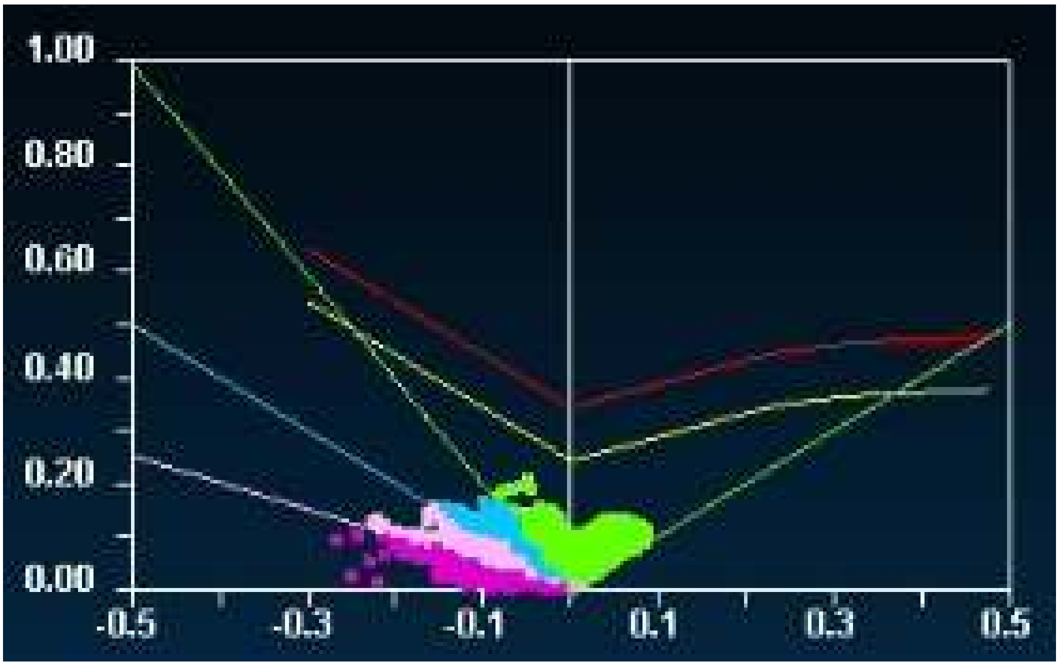


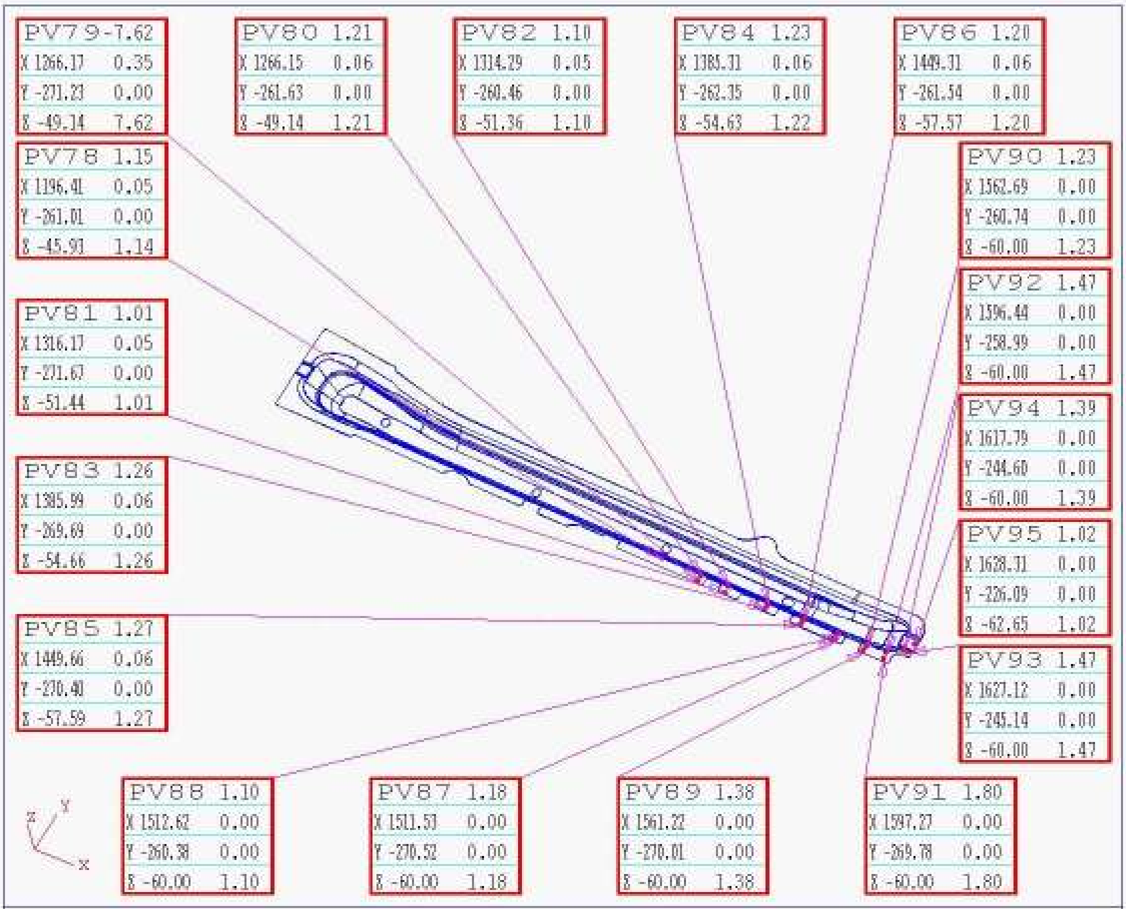
Figure 3.7 – Thickness reduction on stamping simulation using the DP steel. Source: SEMA Toolroom.

Contrary from the CLC curve for the LI material, regions with drawing and cupping is noticed.

The thickness reduction reached values of approximately 0.3mm and the risk of fissure occurrence increases for the DP material.

Comparing the stamping simulations of both materials is noticed that, the product behavior will be very similar, independent of the material. At the dual-phase (DP) material simulation a region addition with bigger thickness reduction is noticed, reaching in some of them to approximate from the beginning of the stamping critical region, but without the risk of ruptures.

After all the laboratory tests, the stamping was realized using the material LI and DP, which have generated two samples which were sent to metrological unities of Tower Automotive do Brasil – Unit at Betim, to generate the three-dimensional of the samples report. The Figure 3.8 refers to DP material.



AREA DE ACOPLAMENTO

Entity	XM	XN	DX	YM	YN	DY	ZM	ZN	DZ	DEV	DIR	TOL-	TOL+
PV78	1196.46	1196.41	0.05	-261.01	-261.01	0.00	-44.79	-45.93	1.14	1.15	* Z+	-0.50	0.50
PV79	1266.53	1266.17	0.35	-271.23	-271.23	0.00	-41.53	-49.14	7.62	-7.62	* Z+	-0.50	0.50
PV80	1266.20	1266.15	0.06	-261.63	-261.63	0.00	-47.93	-49.14	1.21	1.21	* Z+	-0.50	0.50
PV81	1316.21	1316.17	0.05	-271.67	-271.67	0.00	-50.43	-51.44	1.01	1.01	* Z+	-0.50	0.50
PV82	1314.34	1314.29	0.05	-260.46	-260.46	0.00	-50.26	-51.36	1.10	1.10	* Z+	-0.50	0.50
PV83	1386.05	1385.99	0.06	-269.69	-269.69	0.00	-53.39	-54.66	1.26	1.26	* Z+	-0.50	0.50
PV84	1385.36	1385.31	0.06	-262.35	-262.35	0.00	-53.40	-54.63	1.22	1.23	* Z+	-0.50	0.50
PV85	1449.72	1449.66	0.06	-270.40	-270.40	0.00	-56.32	-57.59	1.27	1.27	* Z+	-0.50	0.50
PV86	1449.36	1449.31	0.06	-261.54	-261.54	0.00	-56.37	-57.57	1.20	1.20	* Z+	-0.50	0.50
PV87	1511.53	1511.53	0.00	-270.52	-270.52	0.00	-58.82	-60.00	1.18	1.18	* Z+	-0.50	0.50
PV88	1512.62	1512.62	0.00	-260.38	-260.38	0.00	-58.90	-60.00	1.10	1.10	* Z+	-0.50	0.50
PV89	1561.22	1561.22	0.00	-270.01	-270.01	0.00	-58.62	-60.00	1.38	1.38	* Z+	-0.50	0.50
PV90	1562.69	1562.69	0.00	-260.74	-260.74	0.00	-58.77	-60.00	1.23	1.23	* Z+	-0.50	0.50
PV91	1597.27	1597.27	0.00	-269.78	-269.78	0.00	-58.20	-60.00	1.80	1.80	* Z+	-0.50	0.50
PV92	1596.44	1596.44	0.00	-258.99	-258.99	0.00	-58.53	-60.00	1.47	1.47	* Z+	-0.50	0.50
PV93	1627.12	1627.12	0.00	-245.14	-245.14	0.00	-58.53	-60.00	1.47	1.47	* Z+	-0.50	0.50
PV94	1617.79	1617.79	0.00	-244.60	-244.60	0.00	-58.61	-60.00	1.39	1.39	* Z+	-0.50	0.50
PV95	1628.31	1628.31	0.00	-226.09	-226.09	0.00	-61.63	-62.65	1.02	1.02	* Z+	-0.50	0.50

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	CLIENTE:FIAT AUTOMOVEIS SA	DESENHO N.51758890
METROLOGISTA:ANTONIO CARLOS	D.U.M..	TIPO:
SOLICITANTE:	REL.:587	ASS:

Figure 3.8 – Control of the superficial points using DP steel. Source: Metrology of Tower Automotive do Brasil – Unit at Betim.

The blanks dimensional analyses evidenced the dimensional mistakes on the parts of both steels LI and dual-phase, but the dual-phase material presented a bigger discrepancy mainly with the region of cutting line. Considering that, the block was found on the test phase, the result obtained was the expected on this preliminary phase, which means, the LI material presented a better conformability comparing to DP, but with a minor mechanical resistance after forming, and to guarantee what was specified on the traffic national norms, it would take an addition of 1.20mm to 1.50mm on its thickness. This bigger discrepancy of the dual-phase material dimensional result obtained experimentally and on the mathematical modeling can be due to the big effect of "spring back" tried by this material comparing to LI steel.

4. CONCLUSION

The conformation hardness of the dual-phase steel while the stamping process is compared with LI was verified.

In spite of the stamping simulation indicates that, the behavior from both materials would be similar, in practice the reached result indicates dimensional differences in different points and, that the LI approached more of the objective in the project.

The stampability of the most resistant steels enables the products thickness reduction and consequently the reduction in the vehicle weight, but is necessary a specific mathematical modeling in virtue of "spring back" effect.

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