EVALUATION OF INFLUENCE OF CONTINUOUS ANNEALING PROCESS AND BATCH HEATING IN THE DRAWABILITY OF INTERSTITIAL FREE STEEL

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Abstract. *The objective of this research was to analyze the influence of annealing in the drawability of interstitial free steel (IF). Forming limit diagrams (FLD) and Erichsen cupping tests of the coils made through the continuous annealing process (CAPL) and batch heating (BAF) were compared.*
The objective was achieved by heating of the IF steel produced at USIMINAS with adequate chemical composition and rigorous control of process parameters, in order to obtain excellent drawabilty properties. The sheets were cold rolled and were subjected to continuous annealing process or batch heating. Afterwards, specimens were cut and identified. Samples were stamped at FIAT in a scheduled sequence of presses, and later they aged in processes of automotive painting. Samples for drawability test were taken at various steps of the process.
The texture of the sheets was (111)//ND (gamma fiber); nevertheless, it does not explain the variations in FLD and the results of the Erichsen cupping test in relation with industrial performance (Braga, 2002). A comparison of the position of the FLD curves of the sheet with the profiles of blank deformation permitted fracture prediction of the stamped parts. The experimental results induced changes in the thickness of the sheet used in vehicule manufacture. Production cost was significantly influenced by repair of the stamped parts. The material obtained from continuous annealing showed better performance.
Keywords*: IF steel, deep drawing, automotive.*

1. Introduction

The tendencies for fuel consumption reduction and safety increase of automobiles have forced industries to produce lighter and more resistant cars. With the improvement of fuel performance and car lighter, the emission of CO_2 has been reduced. In addition, automotive design has become more complex, imposing sharper curvatures, which requires materials with better drawability.

Materials with high strength and good formability have permitted stamped products to replace cast, forged and machined pieces in the automobile industry. At the same time, numerical simulation is increasing in deep drawing, which demands knowledge of mechanical properties at different stages and path deformation. Additionally, simulation tests can be compared with industrial performance of material.

The interstitial free (IF) steels were developed to improve the formability of deep drawing products in the last decades (Butterworth, 1982). They have excellent mechanical properties. The yield point is low and elongation is high (USIMINAS, 1996).

The objectives of this work were:

1. To obtain the FLD during whole productive processes of the left front door of vehicles made from sheets that suffer continuous annealing process and batch heating.

2. To analyze the drawability through the Erichsen test in IF steel in the coils obtained from continuous annealing process and batch heating.

3. To compare the performance of IF steel in the coils obtained from continuous annealing process and batch heating through the fraction flaw pieces produced during industrial stamping process.

2. Methodology

The chemical composition of IF steel studied in this work is showed in table 1. The steel was produced in USIMINAS. The carbon, nitrogen, niobium and titanium contents were not enough to characterize aged steel (Najafi-Zadeh, 1992).

Table 1. Chemical composition of alloy studied in this work, % mass.

C	Mn	Si	P	S	Al (sol)	Cr
0.0029	0.0780	0.0119	0.0148	0.0063	0.0376	0.0136
Ni	**Ti**	**Nb**	**V**	**N**	**O**	**Cu**
0.0219	0.0591	< 0.0050	< 0.0050	0.0037	0.0041	0.0136

The final thickness of the hot rolled slab was 3.65 mm. The final temperature was 890 °C, in the austenite field. The coiling temperature of sheets from continuous annealing process (CAPL) was 700 °C and coiling temperature of sheets from batch heating (BAF) was 600 °C. Two coils were obtained from one hot rolled slab. Each coil was divided in two parts top/middle and bottom/middle.

The coils were reduced in 80 % in cold rolling. The sheets were heated at a rate of 10 ºC/s up to 800 °C during the continuous annealing process. They were kept at this temperature during 72 s. Later, the sheets were cooled at a rate of 30 °C/s until 410 °C, and were kept at this temperature during 90 s for homogenization. Later, the sheets were cooled to environment temperature. During batch heating, the piles of three coils were heated at a rate of 30 °C/h until 710 °C. They were kept in this temperature during 12 h. The atmosphere in furnace was constituted of H_2 and N_2. The coils were cooled at a rate of 30 °C/h until 300 °C. Lastly; the sheets were cooled until environment temperature.

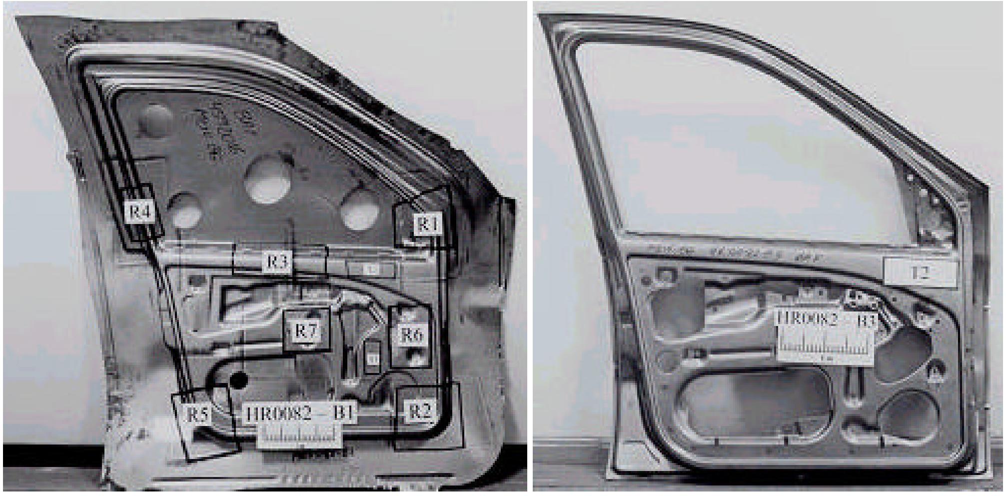
The specimens for FLD were prepared in the guillotine. The rolling direction was parallel to lengthier side. The width changed from 40 to 160 mm with pass 20 mm and 12 square specimens of 180 x 180 mm^2 were also made. Circles with 3 mm diameter were made in the samples through electrochemical etching (Bresciani, Cathlano and Léo, 1977) (Cervelin, Klein, 1982). A sponge was soaked with the electrolyte (Lectroetch 112A) and set on insulating screen above sheet. One electrode in the direct current (TECNIGRAV RB200) was linked to the sheet. Another was linked in the roll that was passed on the sponge to make electrochemical etching in parts in contact with the sheet. Later, the material was washed with Lectroetch Cleaner antirust and the sheets were dried and greased. The ideal circle must have a fine dark trace, without faults. The impressed webs on the specimens were used to measure the strains.

The FLDs were obtained in a universal press with 1000 kN capacity; the die diameter was 250 mm. The blank holder force was 500 kN and feed speed was 25 mm/min. The lubricant used was Tellus 68 Shell that was applied in the both faces specimens. The stamping test was done at the smaller side. The simulation of deep drawing was done with a solid punch (ϕ = 100 mm) with bend radius 50 mm and diameter blank holder was 100 mm. The diameter die was 106 mm with bend radius 8 mm and the diameter drawbead 135 mm. The eight more critical points were obtained in the stamping region and corresponded to 24 tests. The specimens with width from 40 to 140 mm were punched using a blank holder with semicircular section with a 1.5 mm radius while, for the specimens with width from 160 to 180 mm; a 2 mm height triangular section blank holder was used. This test allowed obtaining the eight points of left side of FLD, where deep drawing occurs.

The ironing was simulated that punch whose drawbead section was 2 mm height triangle and die dimensions were 106 x 54, 106 x 85 and 106 x 106 mm for forming three square specimens of 180 x 180 mm. The first and second dies were elliptic and third were circular. The bend radius was 8 mm for all. The oil was supplied until flow over. The blank must be corresponded to a biaxial tensile strain. After the test, the blanks were cleaned from adherent lubricant. Each blank produced one pair of strains (e_1, e_2), that were used to calculate the logarithmic strain (ε_1, ε_2). These strains were measured with digital caliper rule MITUTOYO (precision 0.001 mm). The smaller and larger axes were measured discounting the fracture that must be transversal to direction rolling.

The doors were stamped after electrochemical etching circles. The correspondence between FLD and strain left front door was evaluated. The elliptic formed in the stamped piece were measured with an optic microscopy (magnification 50 times) and the rule with precision 0.001 mm. Eight critical points were choice each kind of forming (ironing or deep drawing) in seven regions (R1 a R7). These regions showed problems during stamping process. The average of the logarithmic strain of the eight points for each region was put in chart. This methodology was applied after spin process (Fig. 1a) and finished product (Fig. 1b).

The ironing tests were made following NBR 5902 standard (ABNT, 1980), in the press Roell + Korthaus of 120 kN. The diameter spherical punch is 20 mm. The internal diameter blank holder was 33 mm. The internal diameter die was 27 mm and bend radius was 0.75 mm. The dimensions sample were 270 x 90 mm respectively. The larger side is transversal to direction rolling. The force in blank holder was kept in 100 kN. The speed of punch was 20 mm/min. The samples were lubricated in both sides, but only regions would be test was greased. The specimens were centralized in relation die and punch. The force and penetration were measured each 2 mm depth until rupture of blank. The result was used to qualify the drawability of material according to NBR 5915 standard (ABNT, 1984).



(a) (b)

Figure 1. Regions were analyzed to obtain pair of logarithmic strains after spin process (a), and finished product (b).

3. Results and Discussion

The fracture FLDs were done with safe coefficient 10 % less than value measured. The left side chart corresponds to deep drawing. The right side chart corresponds to ironing. The strain states were known after the critical logarithmic strains (ε_1 and ε_2) were measured on the stamped pieces, which were classified in relation position in coil and kind of annealing.

The ε_1 values were larger in the materials come from the top of batch heating and bottom of continuous annealing process, which agreed with the success during the stamping process. But, the results of materials come from the bottom of batch heating and top of continuous annealing process were the worst (Fig. 2). The Fig. 3 showed FLD for IF steel in the different thickness: 0.5, 0.65 and 0.77 mm obtained from batch heating and thickness 0.7 mm continuous annealing process. The reduction of thickness went down FLD that increase a probability of fracture.

The FLD from bottom of continuous annealing process was analyzed in Fig. 4a. That showed that R1, R2, R3 and R4 were more demand and ε_1 values were larger. The regions R5, R6 and R7 had similar value between ε_1 and ε_2. In the final product, the strain states changed from ironing to deep drawing to regions R2 and R5 (Fig. 4b).

The FLD from middle of continuous annealing process was analyzed in Fig. 5a. That showed that regions R1 and R5 were more demand. The region R5 suffered deep drawing while R1 was ironing. The regions R2 and R7 had similar value between ε_1 and ε_2. In the final product, the strain states changed from ironing to deep drawing to regions R4 and R5 (Fig. 5b).

The FLD from top of continuous annealing process was analyzed in Fig. 6a. That showed one point from R5 near FLD that indicated a probability of reduction of thickness piece. The regions R1, R2, R3 and R4 were more demand. Their strains were near FLD. There was not addition in the level of strain, but FLD went down. In the final product, the strain states changed from ironing to deep drawing to regions R2 and R5 (Fig. 6b).

The FLD from bottom of batch heating was analyzed in Fig. 7a. That showed that regions R1 and R4 were more demand and ε_1 values were larger. Some points from regions R2, R3 and R7 were below right line to 45º that indicated the probability to earring. In the final product, the strain states changed from ironing to deep drawing to regions R1, R2 and R5 (Fig. 7b).

The FLD from middle of batch heating was analyzed in Fig. 8a. That showed that regions R1, R2 and R4 were more demand. In the region 5, one element was pronounced in the region of deep drawing. In the final product, the strain states changed from ironing to deep drawing to regions R2 and R5 (Fig. 8b).

The FLD from top of batch heating was analyzed in Fig. 9a. That showed that regions R1 and R2 were more demand. And, some elements from regions R2 and R5 suffered deep drawing. In the final product, the strain states changed from ironing to deep drawing to regions R2 and R5 (Fig. 9b).

Indifferent of the position in coil or kind of annealing, all strains were below FLD safe. Then fracture would not occur. After pin process, there were more strains in the ironing region. And, the material suffered more strain in the pin process. All the tests showed that subsequent tasks from pin process had little influence in the profile of FLD to analyzed regions.

The methodology used to obtain FLD has uncertainties like curvature of manufactured specimen, variation of thickness, etc (Almeida, 1998). The punch did not stop immediately due to inertia that makes difficult to measure the length of fracture. Another problem was subjective choice of studied regions.

The ironing Erichsen tests were made following the NBR 5902 standard (ABNT, 1980). The average displacements from sheet of continuous annealing process and batch heating were 12.35 and 12.23 mm and standard deviation de 0.4 and 0.2 mm respectively. These materials would be classified extra deep drawing following NBR 5915 standard (ABNT, 1984), Fig. 10.

The work hardening was analyzed through Erichsen test. The charts were made from load versus displacements. The Fig. 11 showed those materials from continuous annealing process and batch heating did not have difference.

The texture (111)//ND (gamma fiber) obtained from the sheet (Braga 2002) did not explain the variations in the FLD and Erichsen test in relation performance of industrial process.

The percentage of flaw was stratified (Fig. 12). The material identified 4591972 (bottom position from batch heating) showed higher fraction flaw (4.31%), while the material identified 4448830 (bottom position from continuous annealing process) showed the best performance (0%). These results agreed with Fig. 2. The variation of FLD was little and the material bottom position from batch heating was near to fail (Fig. 7a). The material from batch heating showed 28 % of pieces with earring (8 flaw pieces) according to Fig. 7. The fraction flaw pieces were higher in the sheets from batch heating due to the heterogeneity of mechanical properties. The FLDs were obtained to fracture while in the fraction of flaw was considerate necking down and fracture.

During industrial stamping, the averages of percentage of flaw of sheets from continuous annealing process and batch heating were $\mu_{\%CAPL}$ = 0.54% and $\mu_{\%BAF}$ = 2.11% respectively. The averages of percentage of flaw of IF steel stamped without lubricant only protective oil was $\mu_{\%IF}$ = 0.5% (USIMINAS, 1996). The behaviors of sheets from continuous annealing process were more uniform that sheets from batch heating.

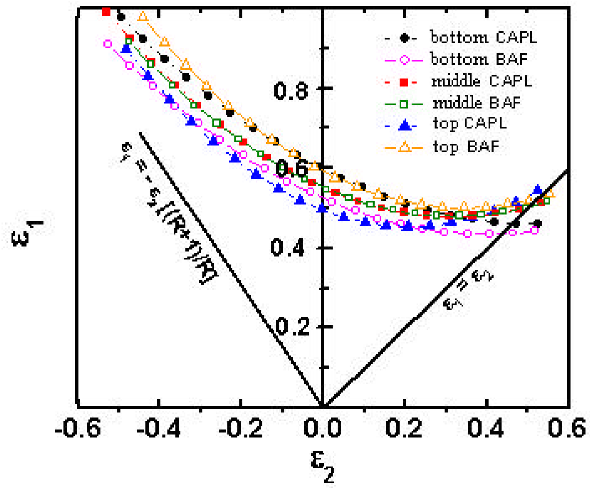


Figure 2. FLD for IF steel with positions bottom, middle and top for material from continuous annealing process or batch heating.

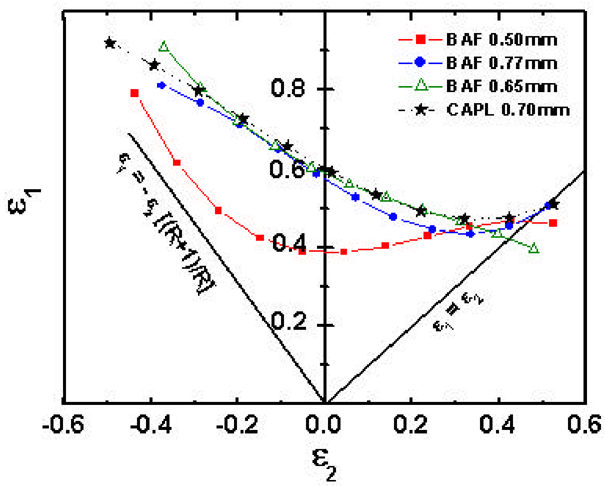


Figure 3. FLD for IF steel with variation of thickness for material from continuous annealing process or batch heating.

These results made the sheets from batch heating were substitutes. The Fig. 13 showed the evolution the percentage of flaws before and later the experiments. The fraction of flaw of sheets from batch heating showed $\mu_{\%LBAF} = 5.19\%$ and $s_{\%LBAF} = 3.7\%$, while sheets from continuous annealing process showed $\mu_{\%LCAPL} = 0.84\%$ and $s_{\%LCAPL} = 0.99\%$.

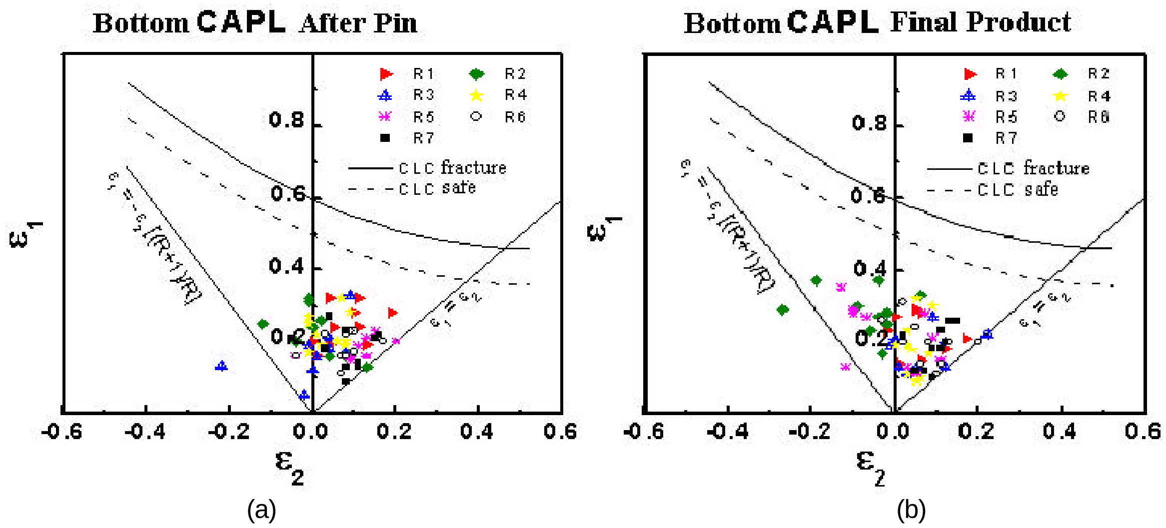


Figure 4. FLD for IF steel in the bottom position from hot coil for material from continuous annealing process after pin process (a) and final product (b), for seven analyzed regions.

The operational costs to evaluate the performance material were divided (Fig. 14):

1) Repair – personnel and material necessary used to repair piece with necking down (FIAT Auto, 1996].
2) Rejects – expenses with failed product.
3) Maintenance – expenses with human and machine stopped to fix die due to changes in the stamping process.

Repair had more impact in the operational cost of continuous annealing process and batch heating. The necking down was flaw that more contributed to repair: 72 % flaw pieces from batch heating (20 pieces) and 100 % flaw pieces from continuous annealing process (7 pieces).

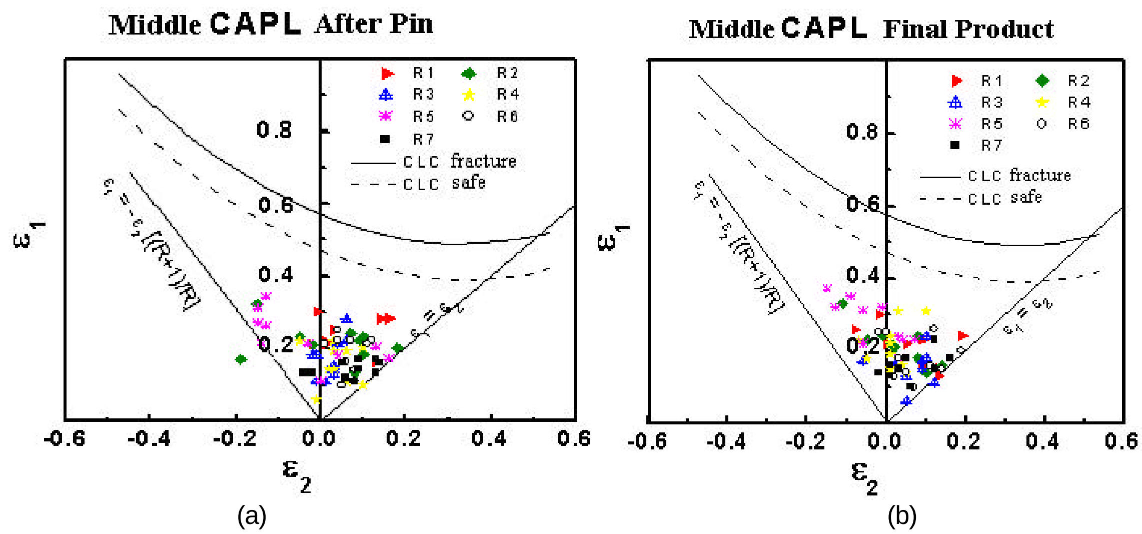


Figure 5. FLD for IF steel in the middle position from hot coil for material from continuous annealing process after pin process (a) and final product (b), for seven analyzed regions.

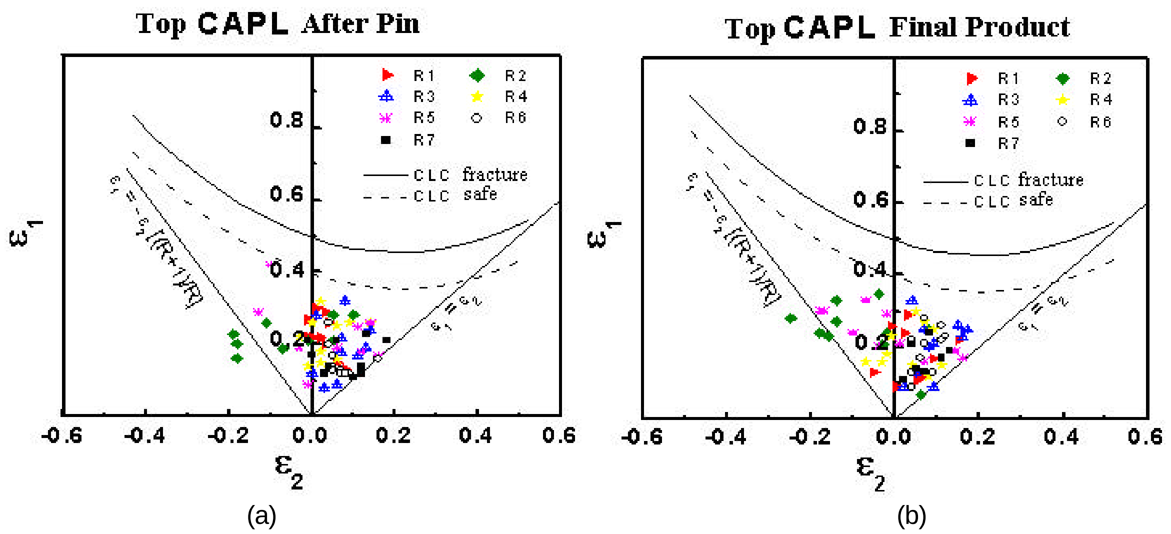


Figure 6. FLD for IF steel in the top position from hot coil for material from continuous annealing process after pin process (a) and final product (b), for seven analyzed regions.

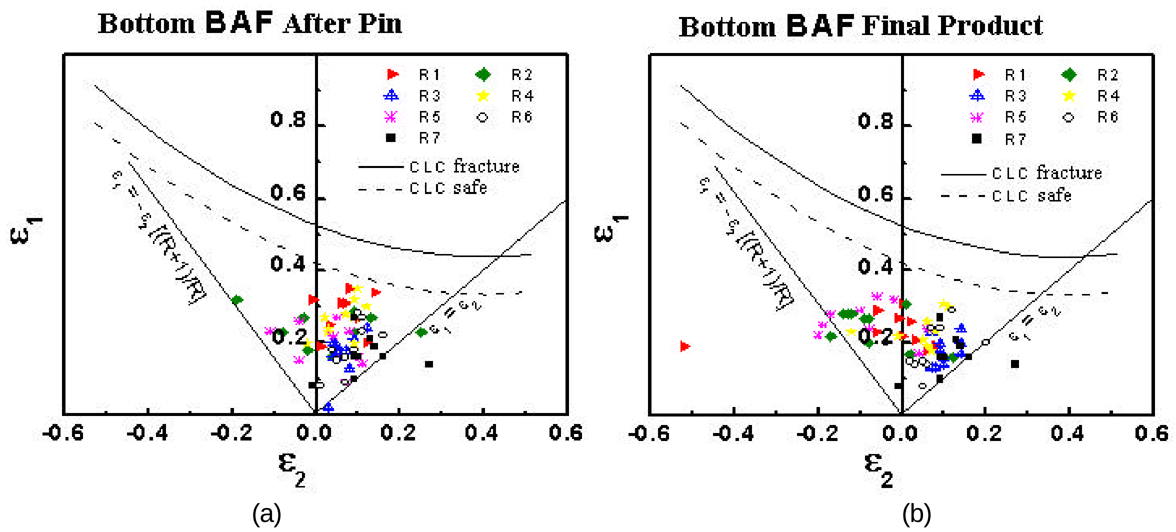


Figure 7. FLD for IF steel in the bottom position from hot coil for material from batch heating after pin process (a) and final product (b), for seven analyzed regions.

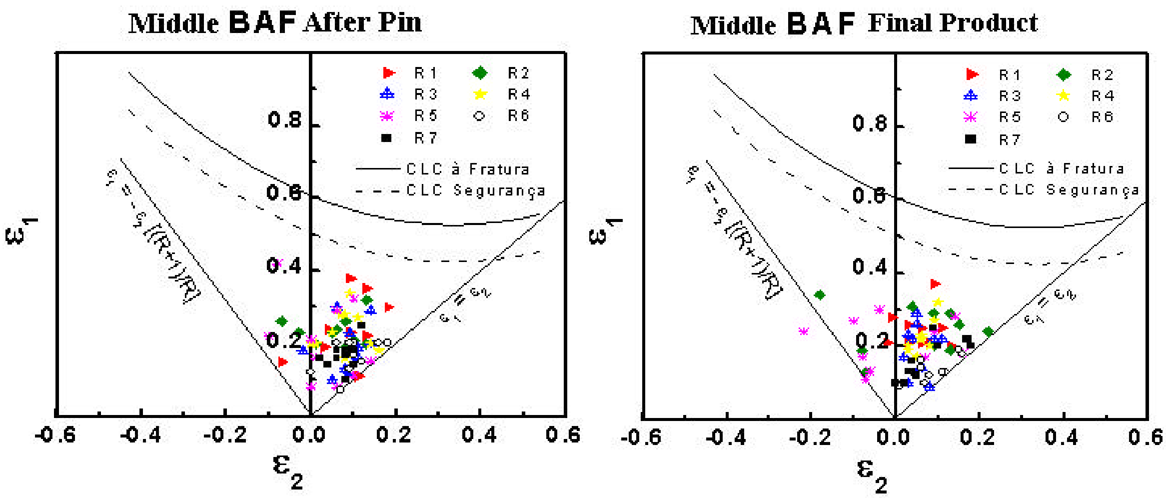
When the thickness were between 0.50 and 0.63 mm independent of annealing, the necking down occurred. The problem would be solved with improvement of drawability and mechanical strength. The Fig. 3 showed that strain states of stamped pieces were below FLD unless the thickness 0.5 mm (Almeida, 1998). The sheets with thickness 0.65 mm could be used to produce framework of front left door of Palio 5 doors. The weight and cost with raw material would be reduced.

The increase of mechanical strength to same thickness like 0.7 mm would be improved mechanical properties of the stamped piece. But, this steel did not gain mechanical strength after aging (Itami, et al., 1995) (Takechi, 1994) Consequential, the results tests of structure vehicle (framework door and panel) to smash, horizontal and vertical, yield collapse settling and vertical fatigue would be improved. The client would be bought a product with more quality and without increase the price. This changes in mechanical strength and thickness would be applied to similar pieces like framework of front right door of Palio 5 doors and front left and right door of Palio 3 doors.

3. Conclusion

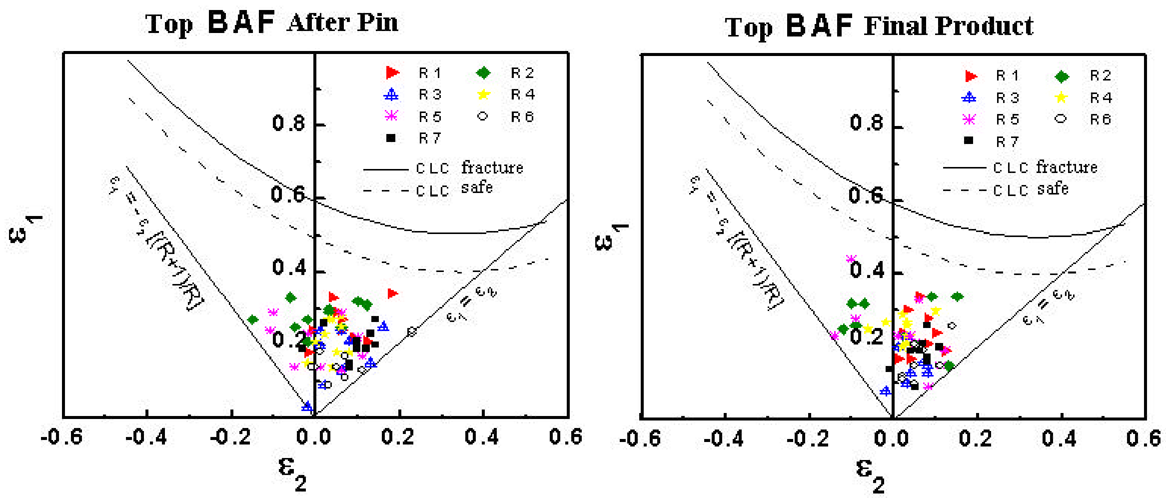
1. The forming limit diagram (FLD) could be used to compare performance of IF steel in industrial stamping process of IF steel from continuous annealing process or batch heating.

2. The Erichsen test could be used to classify the material, however their results could not be correlated with industrial performance.



(a) (b)

Figure 8. – FLD for IF steel in the middle position from hot coil for material from batch heating after pin process (a) and final product (b), for seven analyzed regions.



(a) (b)

Figure 9. – FLD for IF steel in the top position from hot coil for material from batch heating after pin process (a) and final product (b), for seven analyzed regions.

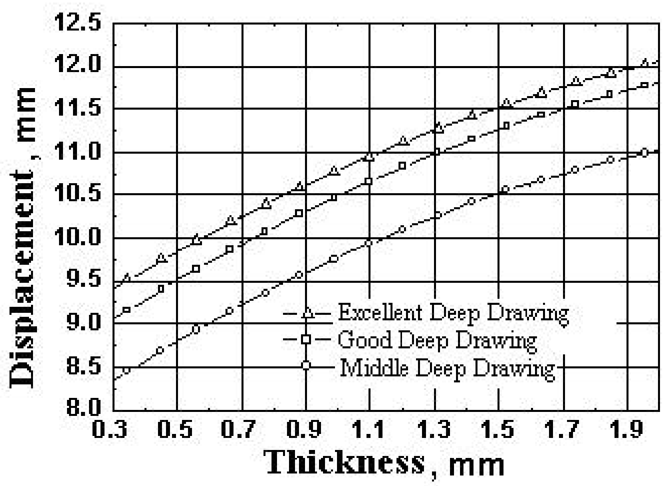


Figure 10. – Classification for drawability for sheet through Erichsen test (ABNT, 1980).

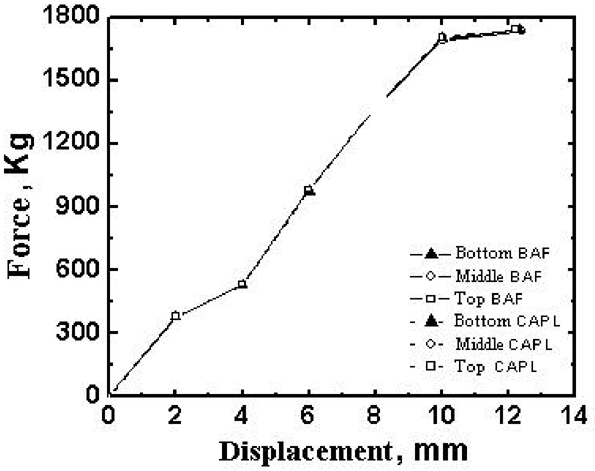


Figure 11. – Load versus displacement to positions bottom, middle and top of hot coil of continuous annealing process or batch heating.

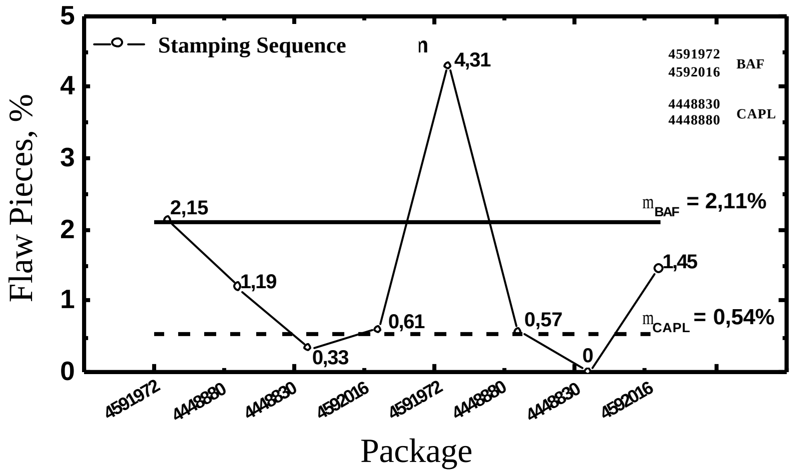


Figure 12. – Evaluation of fraction flaw pieces from different package of IF steel from continuous annealing process or batch heating.

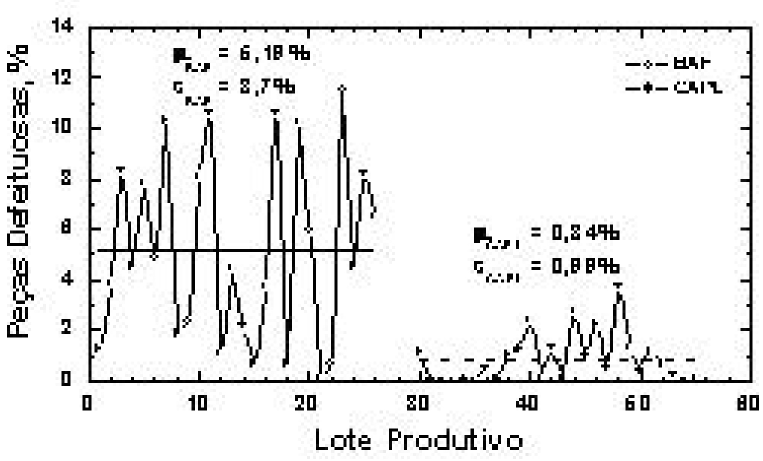
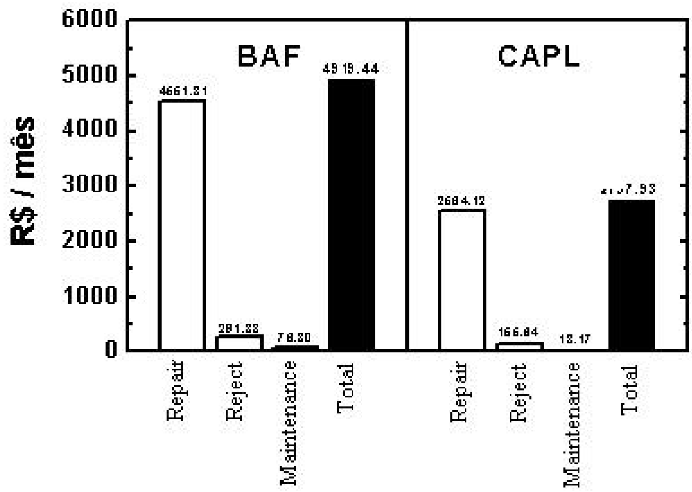


Figure 13 – Evolution of average of fraction flaw pieces for different productive lot in the industrial stamping of IF steel from batch heating (June/2000 to April/2001) and from continuous annealing process (October/2001 to August/2002).



Figures 14 – Comparison of production monthly cost of IF steel from batch heating (BAF) and continuous annealing process (CAPL).

3. The repair had more influence in the operational cost.

4. The steel from continuous annealing process showed better performance in the experiments and industrial process.

3. Acknowledgements

The authors thank FIAT Automobile of Brazil and USIMINAS.

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