CRYSTALLOGRAPHIC TEXTURE AND MECHANICAL PROPERTIES IN HIGH MARTENSITIC DUAL PHASE STEELS

S. Barella, R. Venturini,C. Mapelli

Politecnico di Milano-Dipartimento di Meccanica-Sezione Materiali
Via La Masa 34, 20156 Milano

ABSTRACT

The Dual Phase Steels microstructure consists of a dispersion of a hard second phase (martensite) in a matrix of ferrite or viceversa. This microsctructure gives to these steels optimum combination of strength and ductility. Dual phase steels are known since 1963 but in recent years they have met a growing interest in the applications of the automotive industries, where the high strength is important to reduce the weight of the components and the good formability can improve the quality and the production rate of the final cold forming operations.
The physical and mechanical properties of the Dual Phase steels are closely related to the possible presence of preferential crystallographic orientations produced during the manufacturing process that might induce the anisotropy in their mechanical and physical features. The textures can be developed during the rolling of the sheets in relation of the induced reduction ratio. Also the heat treatment influences the final texture induced in the rolled sheet as a function of the former parent texture.
In the present study the formability and the mechanical properties of two different dual phase steels with high content of martensite volume fraction (60% and 80%) were analyzed to obtain a better understanding of the relationship among texture, microstructure and plastic anisotropy in these steels.

KEYWORDS

Dual Phase, Texture, Deep Drawing, Formability Limit Curve, Steel Sheet, r-value

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INTRODUCTION

Dual Phase steels are obtained by quenching steel sheet from intercritical temperature to produce a microstructure that consists of a dispersion of hard second phase in a matrix of ferrite [1]. The presence of a second phase (martensite) is required to obtain the typical dual-phase behavior: a continuous yielding, a low yield to tensile-strength ratio, a high uniform total elongation and a high work-hardening rate.

The physical and mechanical properties of the metal alloys are closely related to the possible presence of preferential crystallographic textures produced during the manufacturing process that might induce the anisotropy in their mechanical and physical behaviour [2-5]. In fact both heat treatment and rolling might induce texture and then anisotropy in the sheet.

For these steels the attention is particularly focused on the yield strength and formability. One of the more rapid and reliable technique to determine the formability and the mechanical anisotropy is the determination of the plastic stain ratio through tensile tests along the main directions featuring the rolled sheet.

The stretch formability of dual phase steels is excellent in relation to their strength level, but the deep drawability tend to be less impressive for two reason. Firstly, it is difficult to develop the appropriate crystallographic texture necessary for high normal anisotropy because of the alloying additions which are frequently used. Secondly [6,7], even when the texture is suitable, the hard martensite phase perturb the ferrite deformation. The formability depends mainly on the conditions of the ferritic component. However, the presence of the hard phase should modify the plastic behaviour of the softer ferrite.

The rolling texture of the body centered metals (bcc), as ferritic steels, becomes steadily sharper as the imposed plastic deformation increases. The intensity of each component of texture influences the r-coefficient and the related mechanical anisotropy [3]. The presence of the components featured by the planes {111} parallel to the rolling plane increases the r-coefficient and the components featured by {100} decrease this value[3,8,9,10].

The r-coefficient of the cold rolled steel sheets along the three characteristic directions (0°, 45° and 90° with the respect to the rolling direction) are measured to determine the Lankford coefficient (r_m) and the planar anisotropy [11], as well as the textures present in the sheets are measured and then the relation among the relative intensity of texture components and the value of the Lankford coefficient are investigated [12].

1. EXPERIMENTAL PROCEDURE

Two different steel grades have been analysed (Table 1). The two steels are featured by an average minimum tensile strength of 1000MPa (Steel A) and 800MPa (Steel B) in rolling direction.

(% wt)	C	Si	Mn	P	S	N	Cr	Ni	Cu	Mo	Al	Nb	V	B
Steel A	0.134	0.19	1.49	0.017	0.004	0.0024	0.03	0.04	0.01	0.05	0.015	0.01	0.0002	0.0002
Steel B	0.154	0.51	1.5	0.009	0.002	0.0044	0.03	0.05	0.01	0.02	0.046	0.018	0.007	0.0004

Table I. Chemical composition (% wt) of specimens

The steel sheets have undergone the same manufacturing process: hot rolled plastic deformation down to 3.35mm thickness, then they are cold rolled in two passes, the first one to 1.8 mm and the second one to the final thickness 0.7mm. The final annealing has been performed in a continuous line at the temperature of about 800 °C. In this thermal range the steels modify their microstructure and austenite compares at the ferritic grain boundaries [13]. The hot band is then quenched first by a

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cold gas and then by water. The cooling speed has been set at 1000°C/s. Finally, the sheets are also annealed up to 300°C and cooled through an inert gas atmosphere.
In order to evaluate the microstructural differences a SEM analysis was carried out. The tensile tests were carried out by the test machine MTS Alliance RT/100®. The tests were performed on specimens of Steels A and B, obtained from the steel sheet according with ASTM E8, in the direction rotated0°, 45°, 90° from the rolling one. To obtain the r- values the tests were stopped at 5% strain. The collected mechanical properties were: Young Modulus (YM), Yield Stress (YS), Strain Hardening Coefficient (n), Tensile Strength (TS), Uniform Elongation (UE), Total Elongation (TE), Necking (N).
This properties were obtained in according to ASTM E8 and ASTM E111 for the Young Modulus.
The plastic strain ratio or r-coefficient:

$$r = \frac{\varepsilon_w}{\varepsilon_t} = \frac{\ln(w / w_0)}{\ln(t / t_0)} \tag{1}$$

were determined as prescribed ASTM E517 from tensile specimens sampled along 0°, 45°, 90° from the rolling direction. The average r-coefficient was calculated using the following equation:

$$r_m = (r_0 + 2r_{45} + r_{90}) / 4 \tag{2}$$

The possibility and the characteristics of the earing phenomenon were evaluated through the determination of the coefficient of planar anisotropy which is defined as

$$\Delta r = (r_0 - 2r_{45} + r_{90}) / 2 \tag{3}$$

Finally, FLD tests were performed. The blank width are 75mm, 80mm, 100mm, 120mm, 160mm, 190mm, 260mm. The specimens are 260mm long and have been taken in direction parallel to the rolling one.
The crystallographic analysis were performed by the Schultz type X-ray diffraction with 5 degrees steps. The used texture goniometer is a X'Pert Philiphs®. In order to determine all texture characteristics, at least three pole figures were needed. For this reason a powder spectrum was realized to establish the experimental accessible pole figures. The spectrum (carried out through Cu radiation) revealed the {200}, {110}, {211} and {310} diffraction peaks of ferrite. It should also show the martensite diffraction peaks, but it has not been possible to note the peaks corresponding to the martensite lattice. This phenomenon is due to the little difference of the diffraction peaks related to the ferrite and to the martensite. The quantity of carbon present in the studied steel is low enough that the distortion of the martensite lattice is not relevant and thus the phase diffraction peaks of the ferrite and of the martensite overlap.

2. RESULTS

The micrographs (Fig.1) show a structure with the presence of two phases: thin ferritic grains surrounded by martensite. The presence of grains elongated along the rolling direction has been pointed out and this structural organization of the two main structural constituents could be one of the source of the induced mechanical anisotropy.

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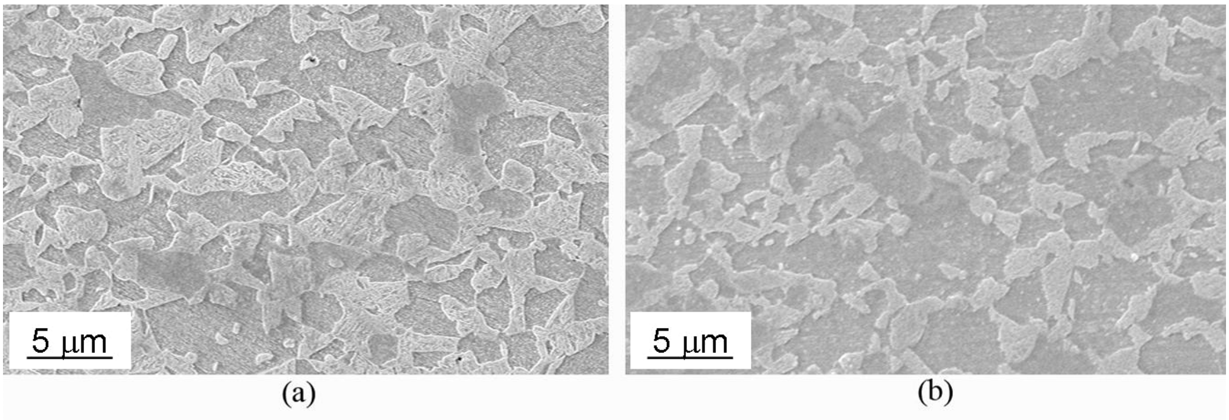

Fig. 1. The micrographs of the studied steel: (a) steel A, (b) steel B along the main directions.

The two steel grades show a different quantity of martensite: 80.1±1.5% for Steel A and 63.1±1.7% for steel B.
In Tab. II are reported the measured mechanical properties (average[1] on the main directions) of the two investigated steels

	Steel A	Steel B
Young's Modulus (GPa)	202 (3)	191(1)
Yield stress (Mpa))	879 (2)	613 (2)
n_1 (1%<ε<3%)	0.14 (0.01)	0.16 (0.01)
n_2 (3%<ε<5%)	0.08 (0.01)	0.11 (0.01)
Tensile strength (MPa)	1043 (6)	795(5)
Uniform Elongation (mm)	3.1 (0.5)	3.7 (0.5)
Total elongation (%)	12.5 (0.8)	14.2 (1.1)
Necking (%)	29.0 (2.9)	47.2 (2.2)
r_m (5%)	0.98 (0.01)	0.85 (0.01)
Δr (5%)	-0,05 (0.01)	-0,29 (0.01)

Table II. Mechanical properties of the two steels after the heat treatment tested at a speed of 25mm/min (the values in round bracket are the standard deviations).

For both steels the Young Modulus assumes the maximum value along the direction perpendicular to the rolling one. The difference among the data related to this direction and the ones at 0° and 45° from the rolling direction can be quantified in average value of 10GPa. Steel A shows a greater value of stiffness than Steel B, because of the presence of a great amount of martensite in Steel A. The stiffness variations along the three directions are the consequence of the different orientation of the grains (especially the ferritic ones) in the materials.

[1] $x = \dfrac{x_0 + 2x_{45} + x_{90}}{4}$

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The yield point (Fig. 2) of Steel A is discontinuous and then the yield stress was evaluated with the offset method while yield of Steel B is continuous and then the yield stress were determined by the autographic diagram method (ASTM E111).

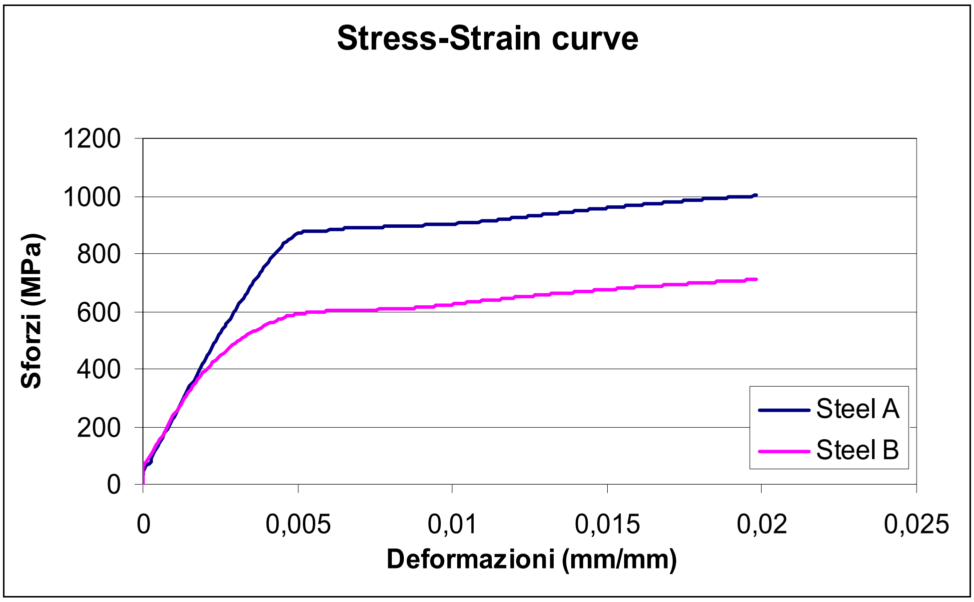

Fig. 2. Stress-strain curve at 2% deformation of the Steel A and Steel B

Steel A show higher mechanical properties than Steel B because of the greater quantity of the contained alloying elements, the related amounts of martensite and the finest microstructure. The best mechanical features are always pointed out along the transverse direction.

The stain hardening coefficient (n) was obtained in two different ranges of deformation: n_1 between 1% and 3%; n_2 between 3% and 5%, because for dual-phase steels, this index is not very accurate to describe the plastic behaviour and then at least two values have to be computed[14].

The greater values of the strain hardening coefficient belong to of Steel B in all cases. This implies that this steel, mechanically less resistant, shows a greater increase of the mechanical properties than Steel A after the strain hardening imposed by to the plastic deformation mechanism. The higher hardening coefficient the more homogeneous is the distribution of the strain along the different directions during the plastic deformation and this provides a better formability.

Tensile strength shows the better behavior of Steel A than Steel B, and the transverse direction shows the higher values. The values of tensile strength confirm the data obtained from the yield stress.

Uniform uniaxial elongation, the elongation in correspondence to the tensile strength, is an interesting feature for the deep drawing steels, actually this well represents the lowest formability limit of the materials [15]. These values include both the elastic and plastic components of the elongation and they can be determined directly from the stress-strain tests. The values of the uniform elongation show a great spread around the mean value. This is due to the sampling procedure, in which the specimens were taken from different parts of the sheet and then the samples obtained from the centre of the sheet show better features than the ones related to the boundary zones. The measurements of Lankford coefficients were carried out at defined strain of 5%. (Tab. II). The experimental data show the greatest values of the r-value along the direction at 45° from the rolling one. The average r- coefficients were calculated, applying the equation (2). Steel A shows greater values than steel B. Ears along the 45 degrees from the rolling direction after the deep drawing tests have turned out from the tests performed. The planar anisotropy was calculated applying the equation (3), for the two steels [16]. The values show the tendency of Steel B to point out the earing phenomenon than Steel A.

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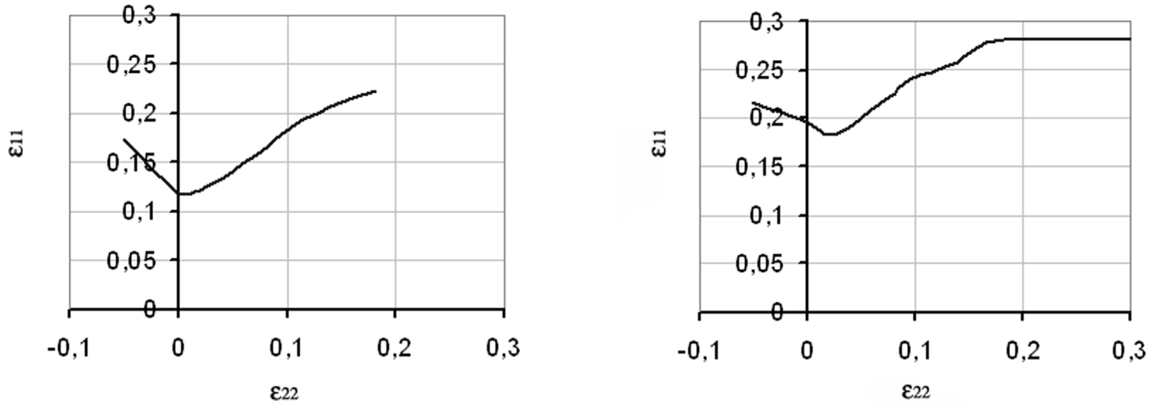
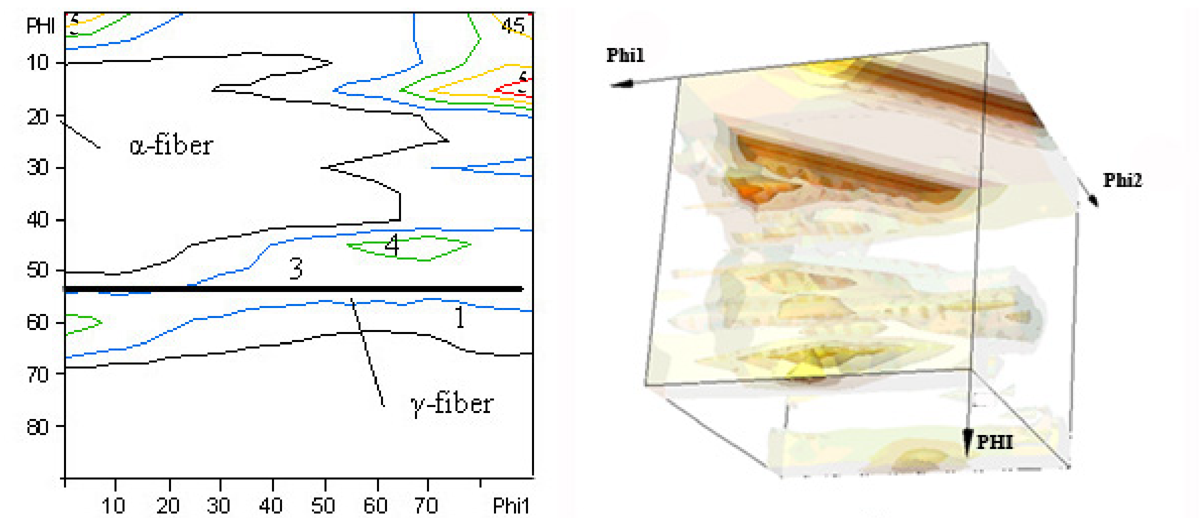
The FLD_0 for the Steel A is 0.12 and for the Steel B is 0.17. The forming limit diagrams of the two steels are also reported (Fig. 2) and show the better formability of Steel B due to the greater amount of ferrite presents in this steel.



(a) (b)

Fig. 3. FLD of the Steel A (a) and Steel B (b).

From the ODF analysis performed by XRD analysis the main component orientations featuring the cold rolled steel were obtained. The ODF (φ_2=45°, notation by Bunge, Fig. 4 and Fig.5) for the two specimens show the sharpest components present in the different steel grades.



(a) (b)

Fig. 4. ODF of Steel A φ_2=45° (Bunge notation) cross section (a) , 3D view (b)The value are in random units.

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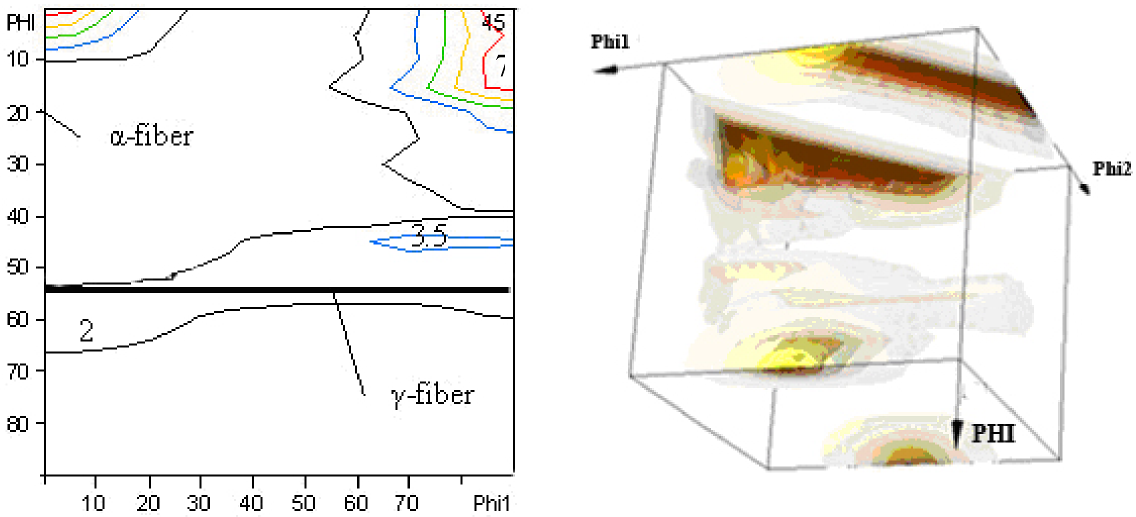

(a) (b)

Fig. 5. ODF of Steel B φ_2=45° (Bunge notation) cross section (a) , 3D view (b)The value are in random units.

For Steel A and Steel B the component with the maximum intensity are {115}<$\bar{5}\,\bar{5}$ 1>. However, this component should be normalized to the component {001}<110>. The component {100}<011> shows a greater intensity in Steel B (~7 in random units) than in Steel A (~5 in random units). Moreover, the intensity of the component {111}<$\bar{1}$01> and of the γ-fiber is the same (~3.5 in random units) for both materials. The component {121}<$\bar{1}$01> is also present and its intensity is lower (~2 in random units) than the first ones.

3. DISCUSSION

The Young Modulus revealed in the two steels appears little low. The trend of the Young Modulus (maximum for rolling and transverse direction and minimum for the 45° one) as a function of the rolling direction is very similar to the one induced by {001}<011> texture[13].
The mechanical tests have shown that, for each material, the best mechanical strength is related to the transverse direction. Along 45° direction there is a better formability and worse strength properties. The strain hardening exponents (n_I), 0.15 for Steel A and 0.16 for Steel B are relatively large if compared to the ones belonging to the other steels featured by a tensile strength of the same order of magnitude. These values could explain the good formability of the two grades, because they imply a uniform and distributed deformation in the sheet before each step of increase of the applied stress.
The r_m values are higher in Steel A (≈ 0.95) than in Steel B (≈ 0.85). It is interesting to underline that *r-coefficients* are maximum, for each material, along the direction rotated of 45 degrees from the rolling one. Steel B shows values of the r coefficient higher than Steel A only along 45°. Planar anisotropy coefficients (Δr) are approximately *0* for Steel A while it is *–0.29* for Steel B. It justifies the isotropic behavior and the tendency to no earing of the Steel A which have been experimentally observed with the negative value of planar anisotropy (Δr) for Steel B is in consistent with the presence of the ears along the 45° after the cup test.
After the determination of *r-coefficients*, yield surfaces have been computed and the section σ_1–σ_2 is reported (Fig.4). This curves are obtained using the relation of Hill's plastic anisotropy (4) through the Lankford coefficients measured for Steel A and Steel B and supposing σ_3 equal to zero.

$$\bar{\sigma} = \left\{ \frac{1}{r_{TD}(1+r_{RD})}\left[r_{RD}(\sigma_2-\sigma_3)^2 + r_{TD}(\sigma_1-\sigma_3)^2 + r_{RD}r_{TD}(\sigma_1-\sigma_2)^2\right] \right\}^{\frac{1}{2}} \quad (4)$$

The yield locus is stretched into the first and third quadrants when the r-values increase [9].
Steel A and Steel B show a different behavior than a mild steel during the deep drawing and it is represented by FLD which underlines a better attitude to face a biaxial state of stress.

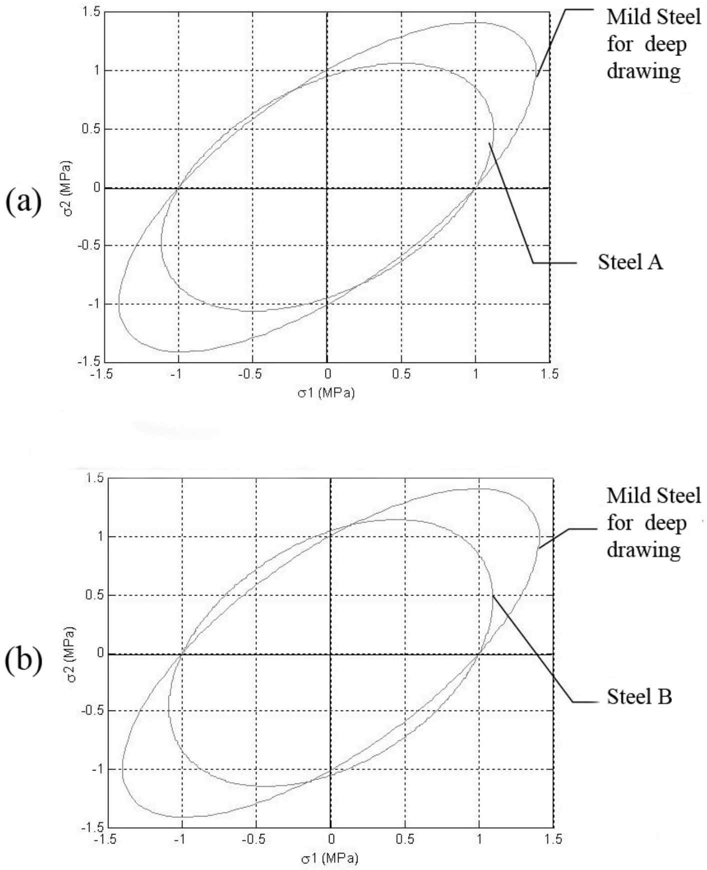

Fig. 6. Comparison between yield surface of mild steel and that of steel A (a) and steel B (b)

FLD_0 value represents the most critical strain state on the FDL. High value of FLD_0 means better formability. This value depends on the *r-value* and mainly on the strain hardening coefficient *n* [16]: the FLD_0 for the Steel A (r_m=0.98; n=0.14) is 0.12 and the one for the Steel B (r_m=0.85; n=0.16) is 0.17.
From the comparison of the components and the intensity of the texture data, between the two steels, it is clear that:

- component {100}<011> is stronger in Steel A than in Steel B;
- component {111}<$\bar{1}$01> and γ-*fiber* texture is the same for both materials.

In Steel B there is a greater presence of {100}<011> than in Steel A, so it causes lower *r-coefficients* in Steel B than that in Steel A.
Component {121}<$\bar{1}$01> is a typical cold rolling texture [2] and it is present in both materials. It does not have a particular effect on r_m values, but it increases $r_{45°}$ so determining an influence on Δr to which rules the earing phenomenon [9].
The collected textural data allow to create a correlation with those obtained from the mechanical tests, particularly with the planar anisotropy coefficients. Slip planes of {100} give the worst drawing quality of deep-drawing sheet [17], while the components featured by {111} are the ideal texture for deep-drawing sheet, because a proper texture is characterized by the slip systems which cause the higher strength along the thickness direction than that in the plane of the sheet.

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The *r-coefficient* is influenced by the reduction path during rolling. High thickness reductions improve the presence of components {100}<011> in the plane of the sheet [18], whereas the lower thickness reduction could be useful in this steels to increase the *r-coefficient* and then to improve the formability of the dual phase.

4. CONCLUSIONS

In the present study the microstructural characterization and the relation among the textures and deformation properties of two different high martensitic (about 60% and 80% volume fraction of martensite) dual phase steels sheet are investigated.

1. The values of normal anisotropy coefficients (r_m) are not high if compared with the traditional behavior of the typical mild steel for deep drawing, but the high values of the stain hardening exponents (n) (0.15 for Steel A and 0.16 for Steel B) give to these steels a good deformation attitude in relaton with the high strength Moreover, the FLD_0 values show the better formability of Steel A than Steel B.
2. The values of the normal anisotropy coefficients (r_m) are related to the components of texture induced in the two sheets. In Steel A the significant presence of components with {111} planes parallel to the rolling plane and the lower presence of the {100} ones than in Steel B justify the higher value assumed by r_m in Steel A.
3. The values of planar anisotropy (Δr), related with the earing phenomenon, is approximately *0* for Steel A while it is *–0.25* for Steel B. For the last one the ears take place in the direction 45° to the rolling one after the deep drawing tests and they are related with the intensity of the components texture present in the materials.

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LIST OF SYMBOLS

ε_w deformation of the tensile specimen along width
ε_t deformation of the tensile specimens along thickness
w_0 initial width of the tensile specimen (mm)
w final width of the tensile specimen (mm)
t_0 initial thickness of the tensile specimen (mm)
t final thickness of the tensile specimen (mm)
r Lankford coefficient
r_m average of the Lankford coefficients among the main directions
r_α Lankford coefficient in a direction rotated by α angle from the rolling one
Δr coefficient of planar anisotropy
φ_1, Φ, φ_2 angle in the ODF analysis with Bunge notation
n strain hardening exponent

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