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Research Article

Limitation of the Experimental Yield Loci for Dual Phase Steel Sheet and its Comparison with Theoretical Results for Original and New Hill Theories

Mohammad Humid J.Mahboba[Ȧ*]

[Ȧ]Technical Institute of Kufa-Iraq

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Abstract

In this research the dual phase steel was produced from low carbon steel 0.1٪C, Then ,real yield behavior for dual phase steel was studied by object sheets metal for different stresses (simple tension stress , balance biaxial tension , plan strain compression). The experimental results for yield loci compared with the original and new Hill's theories, also from this comparison , it was found the new Hill theory gave a good approach with experimental results at (m = 1.8). Moreover increasing the volume of yield Locus with an increase of pre-strain values was done in this research. The results showed that the yield stress in plan – strain compression were higher than the yield stresses in balanced biaxial tension and the later were higher than the yield stresses in a simple tension.

Keywords: *Yield loci, Dual phase steel, Hill theories, Plane-Strain*

1. Introduction

Dual phase steel micro alloy ferrite – martensite has many properties such as high initial work hardening rate , continuous yield behavior , low yield – to –tensile strength ratio σy ⁄ σT and good strength ductility combination (M. Hazratinezhad , *et al* , 2012) , (N.Saeidi, A.Ekrami , 2009) , it also has good formability , harden ability , weld ability ,and fatigue properties (S.Choi, N.Liu, X.Sun, A.Khaleel, 2009), (W.Bleck, 2009) .The fraction volume of marten site(FVM) depend on the annealing temperature and on the cooling rate (S.Gunduz, 2009) , (F.Hayat,I.Sevim , 2012) . Dual phase steel has been used in the automotive body structures in automotive The industry as it is reduces vehicle weight and improved crash resistance (M.Firat, 2012), (Z.G.Hu, *et al*, 2010) , in recent years DP600 applications are widely use in different automobile models Such as Porsche Cayenne ,and Land rover (H.L.Yi , *et al*,2010) . (A.A.Sayed, *et al*, 2012) studied the effect of tempering temperature on the microstructure and mechanical properties of dual phase steels (yield stress, ultimate tensile strength, hardness, elongation). T.Kuwabara and Anther , studied the deformation behavior of 780 Mpa grade dual phase steel sheet subjected to hole expansion¸ investigated both experimentally and analytically to clarify the effect of the material model(anisotropic yield function) on the predictive accuracy of finite element analysis of hole expansion (T.Kuwabara, *et al*, 2011).

2. Basic theory

Yield criteria, known as the law which selects the elasticity limit under combined stresses effected. Yield behavior for isotropic metals was studied by (B.,Dodd and K.Naruse, 1989) , from a previous paper ¸ It was found that the plastic deformation happened when shear stress (τmax.) for metals to rattle constant value by using Tresca criteria:

$$\tau_{max} = constant = \frac{\sigma_y}{2} \qquad (1\text{-a})$$

$$\tau_{max} = \frac{\sigma 1 - \sigma 2}{2} \qquad (1\text{-b})$$

but Von Mises described the yield criteria for isotropic metals by:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = constant = 2\sigma y^2 \qquad (2)$$

where:
σ_1, σ_2, and σ_3 are principles Stresses in three directions.
σ_y is yield stress in rolling direction

2.1 Original Hill theory

(R. Hill, 1979) theory describes the yield criteria for anisotropic metals. Hill's theory depends on this hypothesis: the metals have anisotropy with three orthogonal symmetrical and neglected Bauschinger phenomenon.

Hill yield criterion can be written as dependent on the principle stress in the form:

$$2f = F(\sigma_2 - \sigma_3)^2 + G(\sigma_3 - \sigma_1)^2 + H(\sigma_1 - \sigma_2)^2 + 2LT^2zy + 2MT^2zx + 2NT^2xy = 1 \qquad (3)$$

Where (F,G, H , L , M , N) are Hill's yield function parameters .

*Corresponding author: **Mohammad Humid J.Mahboba**

At sheets forming in the plane (Tyz = Tzx = 0) , but when the sheets formed by tension in rolling direction (Txy = 0) ,thus ,the following equation (3)can be written (R.Hill ,1948) as:

$$2f = F(\sigma_2 - \sigma_3)^2 + G(\sigma_3 - \sigma_1)^2 + H(\sigma_1 - \sigma_2)^2 = 1 \qquad (4)$$

the reason for rewriting the yield function as [14] : of equation (4) is due to the stresses in the plane for sheets (σ 3 = 0).

$$(G + H)\sigma_1^2 - 2H\sigma_1\sigma_2 + (H + F)\sigma y^2 = 1 \qquad (5)$$

When the yield function parameters are expressed in terms of Lankford's anisotropy coefficients for the rolling, diagonal and transverse directions:

$$G = \frac{1}{1+Ro} \qquad (6)$$
$$H = \frac{Ro}{1+Ro} \qquad (7)$$
$$F = \frac{Ro}{R90\,(1+Ro)} \qquad (8)$$

By substitute the equations (6,7,8) in equation (5) to get

$$(1 + Ro)\sigma_1^2 - 2\,Ro\,\sigma_1\sigma_2 + \left(Ro + \frac{Ro}{R90}\right)\sigma_2^2 = \sigma y^2 \qquad (9)$$

The Hill yield criterion can by written as a dependence of the principle stresses in the form (R.Hill, 1948)

$$\sigma_1^2 - \frac{2Ro}{1+Ro}\sigma_1\sigma_2 + \frac{Ro\,(1+R_{90})}{R_{90}(1+Ro)}\sigma_2^2 = \sigma y^2 \qquad (10)$$

$$\sigma_1^2 - \frac{2\bar{R}}{1+\bar{R}}\sigma_1\sigma_2 + \sigma_2^2 = \sigma x^2 \qquad (11)$$

Where R is average anisotropic parameter determined from uniaxial test at Ro,
R_{90}, and R_{45} to the rolling direction:

$$R = \frac{Ro+2R45+R90}{4} \qquad (12)$$

The stresses values in plane strain compression compute from (R.Hill, 1948)

$$\frac{\sigma 2}{\sigma 1} = \frac{K-1}{K+1} \qquad (13)$$
$$K = (1 + 2\bar{R}) \qquad (14)$$

2.2 New Hill theory

New Hill's theory for anisotropic metals was used more than the original Hill's theory in metals, the equation for yield criteria in the new theory can be written: (C.Vial and W.F.Hosford, 1983)

$$2(1 + \bar{R})\,\sigma y^m = (1 + 2\bar{R})\,(\sigma 1 - \sigma 2)^m + (\sigma 1 + \sigma 2)^m \qquad (15)$$

Moreover, compute stresses values in plane strain compression are used this equation:

$$\frac{E_2}{E_1} = \frac{(\sigma_1+\sigma_2)^{m-1} - (1+2\bar{R})(\sigma_1-\sigma_2)^{m-1}}{(\sigma_1-\sigma_2)^{m-1} + (1+2\bar{R})(\sigma_1-\sigma_2)^{m-1}} \qquad (16)$$

Where E1, E2 are the Strain in rolling and transversal direction

In plane stain (E2 = 0)

$$\frac{(\sigma 1 + \sigma 2)}{(\sigma 1 - \sigma 2)} = K \qquad (17)$$
$$K = (1 + 2\bar{R})^{\frac{1}{m-1}} \qquad (18)$$

But Hill's coefficient compute from these equations:

$$m = \frac{ln\{2(1-\bar{R})\}}{ln\{2\left(\frac{\sigma B}{\sigma y}\right)\}} \qquad (19)$$

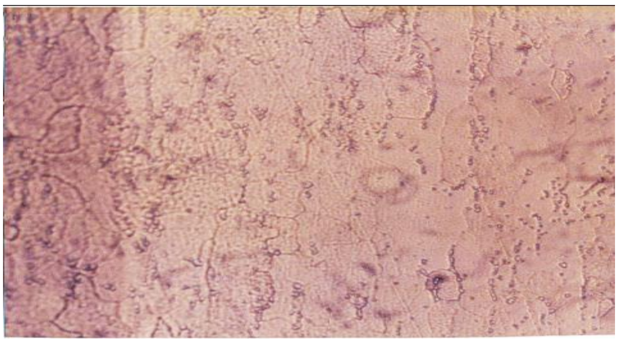
3. Experimental procedures

3.1 Heat treatment and metal

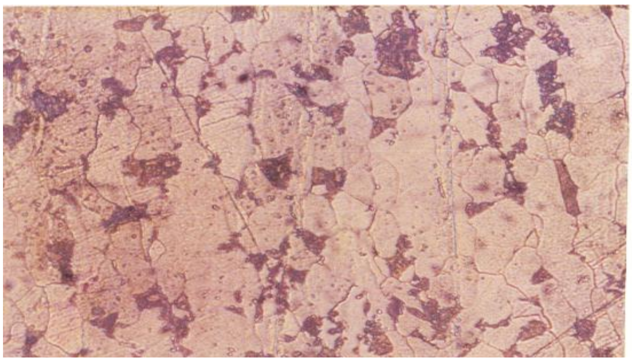
Heat treatment took place in the middle of an electric furnace kind(ESF-PID),Dual phase steel was prepared from commercial low carbon steel (chemical analysis shown in table 1) ,which had (1.5 mm)as thickness .The brine solution which is a mixture of water and commercial salt (NaCL) and in a concentration of 3 Liters of water to half a kilogram of salt .Brine solution which is used as quenching medium for low carbon steel from 800 C° at inter-critical region(α + γ) to steel room temperature ,and figure (1) shows the microstructure for low carbon in figure(a) and dual phase steel in figure (b).

Table 1 Chemical analysis for commercial low carbon steel

C٪	0.109
Si٪	0.164
Mn٪	0.412
P٪	0.019
S٪	0.015
Cr٪	0.631
Mo٪	0.004
Ni٪	0.061
Cu٪	0.052
V٪	0.002
Fe٪	REM.



(a)



(b)

Fig.1 Microstructure for low carbon steel (a) and dual phase steel (b)

3.2 Mechanical test

3.2.1 Tensile simple test

Tensile samples were prepared by cutting rectangular sheets in (0º, 45º, and 90 º) from rolling direction. The tensile samples were equal to the basic dimensions values (ASIM-E8) .At tensile sample test experiments were done on tensile test set (Instron 1195) shown in figure (2), at a strain rate (6.67*10^{-5}) *sec⁻¹ at cross head speed equal to (2mm ⁄min) .Samples had been filled with tensile till broken, and from stress – strain curve to determine the ultimate tensile stress and yield stress at 0.2 ٪ because the yield point in the dual phase steel wasn't clear. Anisotropic (R) in(0º,45º,90º)from rolling direction was computed by measured the wide and thickness by a general microscopic measure device with 0.001 accuracy after the samples were loaded to 25 ٪ more than yield stress .

Fig.2 Instron 1195 for tensile test

3.2.2 Simple compression test

The samples of this test were prepared by cutting the dual phase steel sheet in (10mm) geometrical disc shape by using a punching machine. Nine discs were gathered by using super glue in a cylindrical shape. Each cylinder made was left in a very calm place to dry for thirty minutes. All the cylinders were re-shaped by the lathe machine in order to get (h ⁄d = 1.3) ratio (W.Johnson and P.B.Mellor , 1980) .The compression test was performed by using (Instron 1195) figure(2) ,all tests were performed at cross head speed equal to (2mm ⁄min) at which the strain rate equal to (6.67*10^{-5}) *sec⁻¹ .After the sample reached the plastic deformation zone , the load was released and it's magnitude was recorded then the diameter and the height of the sample were measured. The yield stress was calculated by dividing the load on the cross section area of the sample after deformation. However, the strain thickness was calculated from the following formula:

$$E_t = -\frac{t}{to} \tag{20}$$

Where to and t are the thickness of sample before and after compression

3.2.3 Plan-strain compression test

The plan strain compression tests were conducted of the welding shop in Kufa Technical Institute to study the yield stress in rolling direction and transverse directions. To perform this study, forty samples with(36 x 40)mm dimension were made from dual phase steel sheet , twenty of these samples were shaped in the rolling direction whereas the others were in the transverse direction .The thickness of sheet metal was(1.5 mm) ,therefore the die width was calculated to be(6 mm) according to the formula (t ⁄ b) equal from ¼ to ½ (W.Johnson and P.B.Mellor , 1980) , where(t) is the sheet metal thickness and(b) is the die width .From the die width the sheet metal width(w)must be (36 mm) according to (w ⁄ b≥ 6) (W.Johnson and P.B.Mellor , 1980) . A 50 tones Dartec machine figure(3)was used to do the plan strain compression tests at cross head speed (0.2 mm), each sample was fixed in the test die and the machine punch was allowed to press the sample .The process of punching left a deformed groove along the die length .

Fig.3 Daratec machine for compression test

3.2.4 Pre-stain test

Pre-strain tests were conducted on tensile samples to study stress stain curve of dual phase steel. Two values were chosen for pre-strain before and two values after yield points, in addition to the pre-stain at yield point which was determined at strain ratio equal to 0.2 ٪. Figure (4) shows the tension sample ,this sample was tied between the(Instron 1195) machine jaws and cross head and was allowed to move until the sample was broken down , also the tension machine calibrated at cross head speed(0.2 mm ⁄min) whereby the stain rate was equal to (6.67*10^{-5}) *sec^{-1} .

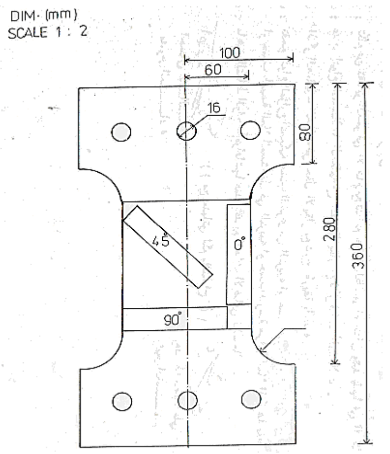


Fig.4 Sample tension for pre –strain with different rolling direction

4. Results and Discussion

From figure (5) it can be deduced that the experimental yield loci of the yield for the dual phase steel differ in their values of pre-strain. The yield loci showed an elliptical shape. However, it expanded as the pre-strain value increased. This increase occurs as a result of the anisotropic of the dual phase steel sheet)(R)which increased as the pre-strain increased ,the same result was attained by (Z.Karastojkovic and B.Perovic, 1980) when they studied the anisotropic of yellow and red copper , their finding showed that the (R) increased by the increase in the deformation ratio .Figure (6)shows a comparison between the experimental results of the yield loci and Hill's theories(New , Original) for dual phase steel at pre-strain ratio where pre- strain occurred before the yield point at 2.1٪ pre-strain and after the yield point at 20.5 ٪ pre-strain , From the above comparison it can be concluded ,that the new Hill theory gave the best approach with experiment results .The experiment results were significantly different from that of Hill theories at the zone that included the plan stain compression and the simple compression , whereas the differences were higher at the simple compression area . However, the results also showed little differences between the experiment and Hill theories results at the simple tension area .A (9 ٪) difference was detected between the experimental results and the original Hill theory results , while the new Hill theory results showed only (4 ٪) .

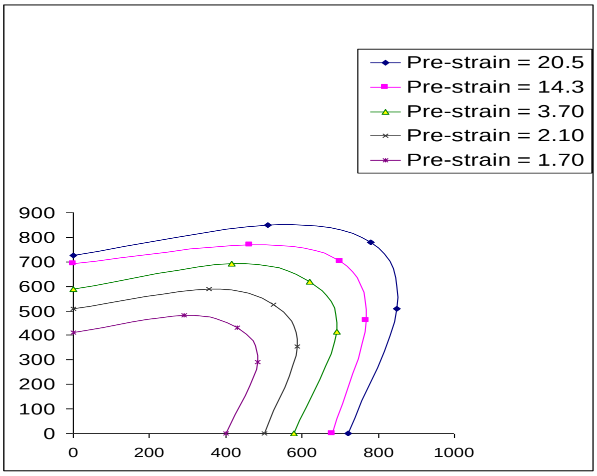


Fig.5 The experimental yield loci for the dual phase steel differ in their values of pre-strain

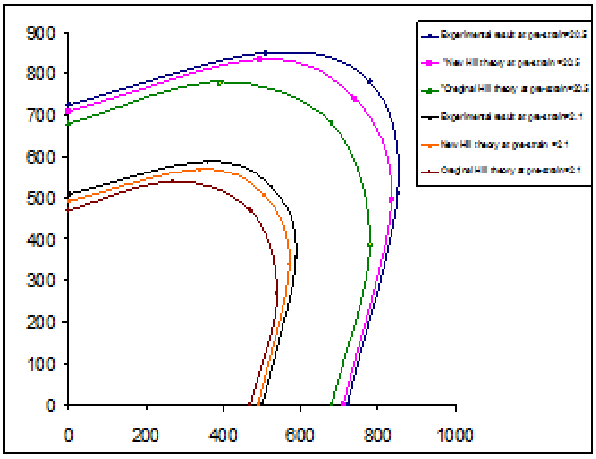


Fig.6 The comparison between the experimental results of the yield loci and Hill's theories (New, Original) for dual phase steel

Conclusions

The following remarks can be concluded:

1. The yield loci show an elliptical shape for dual phase steel.
2. The new Hill theory gave the best approach with experimental results at Hill's coefficient equal to (m = 1.8).
3. In case of plane strain compression for dual phase steel sheet, the yield stress was higher than the simple tension and the simple compression.
4. The anisotropic (R) values differ with the rolling direction (0º, 45º, 90º) for dual phase steel.
5. The yield loci for dual phase steel were expanded with a pre-strain increase.

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