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Performance Evaluation of Yield Function and Comparison of Yielding Characteristics of SS 304 in Annealed and Unannealed Conditions

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Abstract: Sheet metal forming forms in numerous industries like vehicle depend on the yielding of the sheet metals when strained. Yielding is portrayed by plastic flow of the materials when strained. The yield point if there should be an occurrence of uniaxial tension can be effectively decided from the pressure strain diagram, yet if there should arise an occurrence of multi-axial stresses, it gets complicated. A connection between the principal stresses is required determining the conditions under which plastic flow occurs. This intricacy is tended to by the anisotropic yield capacities. Likewise, the tests used to acquire yield loci might be costly and time taking in such case these yield capacities end up being exceptionally viable. The yield criteria additionally help in deciding the planar distribution of yield stresses and anisotropic coefficients, which gives a decent gauge of these mechanical parameters without having to through the pain of trial assurance. This project aims at using Hill 1948 criterion to obtain the Yield surface Diagrams for SS304 in annealed and original state and subsequently obtain the planar distribution of the uniaxial yield stress and anisotropic coefficient. The yield surface diagram for both the specimens was successfully obtained and as indicated by them, the formability of SS304 in an annealed state is higher. In addition, the performance of Hill 1948 criterion was evaluated and it was found to be accurate for the prediction of r-value distribution but at the same time, it has high inaccuracy for the prediction of uniaxial yield stress with orientation.

Introduction

The finding of plastic flow state for sheet metal is critical to examine its yield qualities. Yielding is portrayed by the plastic flow of the materials when stressed. [2][3][9]. If there should be an occurrence of uniaxial stress, the purpose of yield is advantageously acquired from the stress-strain curve. However, when multi-axial stresses are available, it turns out to be more complex and requires development flow equation. A connection between the principal stresses is required indicating the conditions under which plastic flow happens. This unpredictability is tended to by the anisotropic yield capacities. In addition, the analyses used to get yield loci might be costly and time taking; in such case, these yield capacities turn out to be exceptionally powerful. The yield criteria likewise help in deciding the planar distribution of yield stresses and anisotropic coefficients [1][3][12], which gives a decent gauge of these mechanical parameters without having to through the pain of exploratory assurance. Such a relationship is typically characterized as a verifiable capacity (known as the yield work [3]: F (σ_1, σ_2, σ_3, Y) = 0, Where σ_1, σ_2, σ_3 are the primary entities, and Y is the yield stress acquired from a basic test (strain, pressure or shearing). The connection can be portrayed as a surface in a 3-D space where the focuses lying at first glance (F=0) allude to the plastic condition of the material, the focuses lying inside the surface (F<0) allude to the elastic state and the focuses outside the surface (F>0) have no significance. On account of plane stress (e.g. $\sigma 3 = 0$) the yield surface reduces to a curve in the plane of the important anxieties $\sigma 1$ and $\sigma 2$. Since its initiation, there have been a few yield criteria proposed, the most generally utilized [2] are: Hill 1948[3][7][9], Hill 1990[3], Barlat 1989[9], and BBC 2000[2]. The pioneer of the development of anisotropic yield criteria was Hill [2]. He proposed in 1948 a quadratic formulation. He improved his models in 1990[3] and 1993[7-15]. Yield functions characterize the beginning of the yielding or the begin of plastic deformation. The execution of a yield work is one of the key issues for the sheet metal forming. In the course of the most recent 100 years, many yield criteria were produced for the portrayal of sheet metal practices particularly for exact modelling of anisotropy, for example, Hill's (48, 79, 90, 93) yield criteria [16-18]. This study aims at using Hill 1948 criterion to obtain the Yield surface Diagrams for SS304 in un-annealed and annealed state and subsequently obtain the planar distribution of the uniaxial yield stress and anisotropic coefficient. In addition, the performance evaluation of both the distributions will be done. This project aims to compare the yielding characteristics of SS304 in annealed and original state using Hill 1948 criterion as to determine how annealing is affecting the yield surface diagram and in turn its formability and it also covers the evaluation of two of the accuracy indices of yield function to assess its performance. Different yield functions give different accuracies for r-value distributions and yield stress distribution. In such case, the application of accuracy indices would prove beneficial to choose the yield function as per our needs.

Yield Surface Diagram

A yield model communicates a connection between the stress parts exactly when plastic 'yielding' happens. If there should be an occurrence of a multi-axial stress state, it is increasingly hard to characterize a basis for the progress from the versatile to the plastic state. A connection between the principal stresses is required indicating the conditions under which plastic stream happens. Such a relationship is typically characterized as a certain capacity given by equation 1 (known as the 'yield function'):

$$F\,(\sigma_1, \sigma_2, \sigma_3, Y) = 0 \tag{1}$$

Hill 1948 yield criterion

In 1948 Hill proposed an anisotropic yield criterion for sheet metals [3][6]. The material is supposed to have anisotropy with three orthogonal symmetry planes. The yield criterion is expressed by a quadratic function given by equation 2 and equation 3 [3][6] [12]:

$$2f(\sigma_{ij}) \equiv F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + H(\sigma_{11} - \sigma_{22})^2 + 2L(\sigma_{23})^2 + 2M(\sigma_{31})^2 + 2N(\sigma_{12})^2 = 1 \tag{2}$$

Here, f is the yield function; F, G, H, L, M and N are constants specific to the anisotropy state of the material, and x, y, z are the principal anisotropic axes.

Yield Criteria: Quality Index

To have a complete assessment evaluation, the individuals from the CERTETA inquire about the group have built up a worldwide exactness list characterized as pursues [3]:

$$\beta = \phi + \delta + \gamma \tag{3}$$

Where: φ is an accuracy list related to the expectation of the yield locus shape in the plane of the primary anxieties; δ is the accuracy list related to the forecast of the planar distributions of the uniaxial yield stress; γ is the accuracy Index related to the prediction of the planar distribution of the uniaxial coefficient of plastic anisotropy.

Experimental Procedure

The SS 304 sheet material supplied was tested for its elemental composition by Optical Emission Spectroscopy (OEM) and was confirmed. Annealing was performed at a soaking temperature of 1050° C for a dwell time of 30 minutes in an electric muffle furnace. The specimen was then cut along different orientations as per the ASTM E8 standards for mechanical testing.

Calculation of r - values

The width and thickness of the specimen before and after the 20% elongation is measured for all the orientations. The initial and final width and thickness values are evaluated using equation 4 to 6.

$$r_0 = \ln(w/w_0)/\ln(t/t_0) \tag{4}$$

$$r_n=(r_0 + 2r_{45} + r_{90})/4 \tag{5}$$

$$\Delta r = (r_0 + r_{90} - 2r_{45})/2 \tag{6}$$

Where r_θ is the coefficient of anisotropy at an angle θ from rolling direction, w is for width and t for thickness. Δr is the planar anisotropy.

Obtaining YSD

The hill 1948 equation 7 to 12 is used to obtain YSD. The values are fed into the equation 13 and 14

$$\sigma_1^2 - [(2r_0/(1+r_0))\sigma_1\sigma_2] + [(r_0(1+ r_{90}))/(r_{90}(1+ r_0))]\ \sigma_2^2 = \sigma_0^2 \tag{7}$$

Planar distribution of r vs. θ & σ vs. θ

Parameters required F, G, H, N, r_0, r_{45}, r_{90}

Relationship between G & H:

$$G+H=1 \tag{8}$$

$$\text{Thus, } G=1/(1+ r_0) \tag{9}$$

$$F=r_0/r_{90}(1+r_0) \tag{10}$$

$$N= (1+2r_{45})(r_0+r_{45})/2r_{90}(1+r_{90}) \tag{11}$$

$$Y_\theta = [(Y(h))/(G\cos^2\theta + F\sin^2 \theta + H(\cos^2 \theta - \sin^2\theta) + 2N\sin^2 \theta\cos^2 \theta)^{0.5}] \tag{12}$$

Y_θ/ Y(h) can be calculated and graph plotted between Y_θ/ Y(h) and θ.

$$r_\theta= [(G\cos^4 \theta + F\sin^4 \theta + H\cos^2 2\theta + (1/2)(N\sin^2 2\theta))/(G\cos^2\theta + F\sin^2\theta)] - 1 \tag{13}$$

$$r_0 = H/G;\ r_{90} = H/F;\ r_{45} = N/(F + G)- \tfrac{1}{2} \tag{14}$$

Where F, G, H and N are material Parameters depending on r-values. Similarly, r_θ can be calculated and graph plotted between r and θ.

Performance evaluation

Experimental and theoretical values of σ_0, σ_{45}, σ_{90} and r_0, r_{45}, r_{90} for unannealed and annealed are obtained using equation 15 and 16. δ is computed using the formula:

$$\delta =\sqrt{}\ [\ \Sigma^n{}_1((\sigma^e{}_{\theta i} - \sigma^t{}_{\theta i})/ \sigma^e{}_{\theta i})]^*\ 100[\%] \tag{15}$$

γ is computed using the formula

$$\gamma = \sqrt{}\ [\ \Sigma^n{}_1((r^e{}_{\theta i} - r^t{}_{\theta i})/ r^e{}_{\theta i})]^*\ 100[\%] \tag{16}$$

Where δ, γ are the accuracy index associated with the prediction of the planar distribution of the uniaxial yield stress, and anisotropic coefficients respectively.

Results and Discussions

Material Composition

Table 1: Chemical Composition of SS304

Element	C	Mn	Si	S	P	Cr	Ni
Composition (%)	0.028	1.591	0.581	0.009	0.042	18.458	8.595

Manganese (Mn) composition above 2% imparts brittleness to the steel, but here it is within safe limits. Its carbide forming tendency is the least but decreases the critical temperatures for austenite formation and counteracts the brittleness caused by sulfur. Silicon (Si) increases the hardenability of the steels, it is known for its ability to resist oxidation in steel. Sulphur (S) has deleterious effects on steel as it forms sulfide along the grain boundaries and makes the steel brittle. Its effect is avoided by using Manganese. Phosphorous (P) is present in a small amount which increases the strength and hardness of steel. Chromium (Cr) is an excellent carbide former, and it imparts very good corrosion resistance properties to the steel. Nickel (Ni) strengthens and toughens the ferrite phase. It increases the heat treatability of the steel by reducing the cooling rate required for cooling.

Yield Surface Diagram

In Fig. 1, the yield surface diagrams obtained for both the specimens depict the plastic state of the sheet metals in the presence of multiaxial stresses. It is evident from the yield surface diagram that the curvature of the graph near the equi-biaxial zone is greater for SS304 and less for SS304 annealed, which means transition from biaxial zone to plain stress zone would take more time in case of annealed SS304 hence resulting in greater formability [5].

Planar distribution of r-values and Uniaxial Yield Stress

The relationship between r & θ and Y_θ/ Y(h) & θ was obtained from calculations. MS-Excel was then used to obtain graphs between r & θ and Y_θ/ Y(h) & θ.
In Fig. 2, the planar distribution for the SS304 annealed, the peak occurs along the rolling direction itself, and the r value decreases further with the change in orientation. For the unannealed material, the graph attains maxima around 45 degrees of orientation and then decreases continuously.
In Fig. 3, the graph obtained for annealed SS304 lies above SS304, which in itself is inaccurate since the annealing decreases the yield stress of the material. However, it predicts similar trends for the variation yield stresses. The dip occurs around 45 degrees for both the materials and increases as the perpendicular direction is reached.

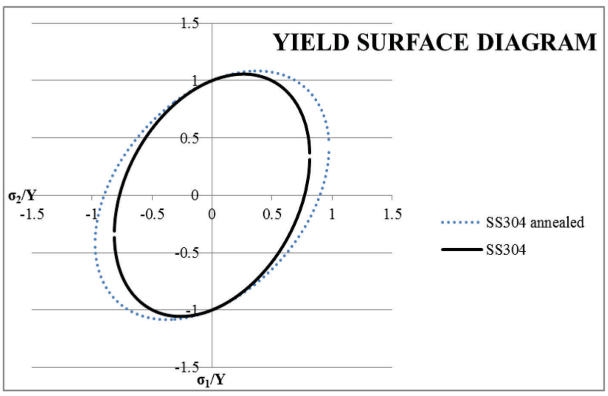

Fig. 1. Yield Surface Diagram

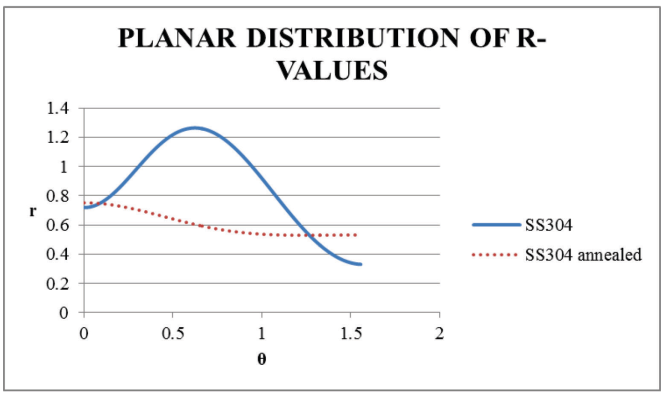

Fig. 2. Planar Distribution of R Values

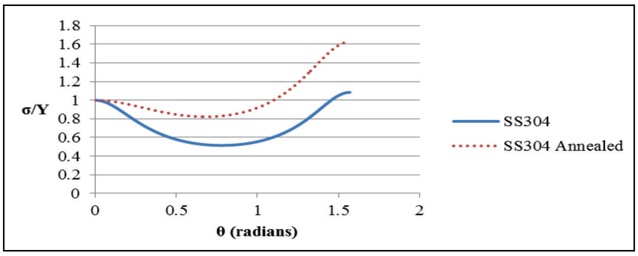

Fig 3. Planar Distribution of Yield Stress

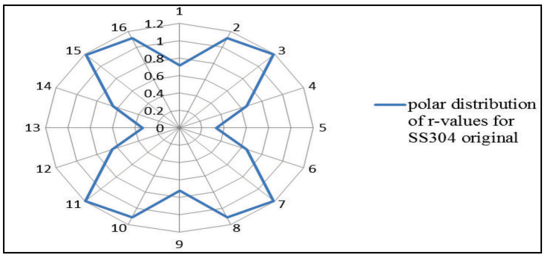

Fig 4. Polar Distribution of R Values Unannealed

Performance evaluation of the Yield Function

The two performance coefficients are measured for both the specimens. From the calculations, it is observed that the values for δ are moderately high (36% and 15%), had the yield stress values in the 90^{o} orientation been included, the value had been even higher. It shows that Hill 1948 criterion is not fit for yield stress prediction with such amount of inaccuracy. The reason for this can be explained by referring to the uniaxial yield stress equation for this criterion. It can be seen that the formula only accepts F, G, H and N as parameters whose value depends on r-values. Thus, there is no variable accepting yield stress as the parameter hence owing the inaccuracy. If we take a look at the other performance coefficient γ, we will find it to be very less (9% and 4%). Thus Hill 1948 equation is highly accurate in predicting the r-values for obvious reasons. The particular equation accepts F, G, H and N values which accept r-values as their parameters, which defines the function when and gives it the required flexibility.

Polar Distribution of r-values

Polar distributions were plotted with the help of values obtained from r versus θ calculations. From Fig. 4, and Fig. 5 it can be seen that the graph obtained for SS304 original is symmetrical with sharp variations at 45^{o} orientations, which suggests that the earring amplitude or the earring tendency is higher along this orientation. The distribution for annealed SS304) is relatively smooth but it has some amount of asymmetricity.

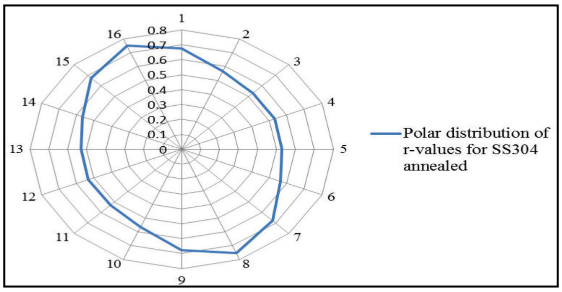

Fig 5. Polar Distribution of R Values annealed

Conclusions

The yield surface diagram for both the specimens was successfully obtained and as indicated by them, the formability of SS304 in an annealed state is higher. In addition, the performance of Hill 1948 criterion was evaluated and it was found to be accurate for the prediction of r-value distribution but at the same time, it has high inaccuracy for the prediction of uniaxial yield stress with orientation. The reason for this can be explained by referring to the uniaxial yield stress equation for this criterion. It can be inferred from the formula, that it only accepts F, G, H and N as parameters, whose value depends on r-values. Thus, there is no variable accepting yield stress as the parameter hence owing to the inaccuracy. Hill 1948 equation is highly accurate in predicting the r-values for obvious reasons. The particular equation accepts F, G, H and N values which accept r-values as their parameters, which define the function well and give it the required flexibility. Hence, it can be inferred that to predict the planar anisotropy distribution, Hill's equation is highly accurate. However, for yield stress distribution, we have to look for some other criteria with more parameters related to yield stress and more flexibility.

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