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Comparison of Formability of Sheet Metals of Different Grades used in Automotive Industries

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ABSTRACT

The formability of three steels namely IF steel , SS430 and EDDQ are analysed and compared using forming limit strain curve (FLC) through forming limit stress curve (FLSC) theoretically with the parameter value **m = 3** (strain rate sensitivity or yield equation constant).

1. Introduction

The forming- limit curve (FLC) is a very useful diagnostic tool for trouble shooting in sheet metal forming industries. A number of studies have been made to construct forming –limiting cures for various sheet metals. These methods generally lack simplicity and also have limitations in terms of applicability in an integrated computer modeling environment. The FLC depends on the pre-strain and the strain path . However, a forming – Limit Stress Curve (FLSC) is independent of the strain path, and FLCs can be derived from the FLSC for several strain paths.

In this paper, a new method of constructing FLCs is proposed in terms of readily measurable material properties from a tensile test from the knowledge of a single limit yield stress, e.g., the maximum tensile stress, a limit yield stress curve can be determined, assuming that the material follows Hill's yield criterion and isotropic hardening model. The FLC can now be developed by using the Holloman strain-hardening equation .Hill's anisotropy yield criteria and the Levy-Mises equation .

Table 1 : Mechanical Properties of steels Tested

Sl.No.	Sheet Metal Thickness	r	$\bar{\sigma}_L$	n	K
1.	IF STEEL – 0.85 mm, non-coated	2.09	572	0.32	578
2.	SS430 – 1.2 mm	1.06	496	0.228	589
3.	EDDQ - 1.2 mm	1.67	418	0.141	480

2. Nomenclature

K	-	Strength coefficient of material constant
n	-	Strain hardening exponent.
m	-	Strain rate sensitivity or Yield Equation constant .
R^N	-	Relative density (N=1.8-2.0)
r	-	Plastic anisotropic ratio or radius of curvature of the neck.
p	-	exponential parameter involved in r- value.
$\bar{\sigma}_L$	-	Equivalent limit stress
$\bar{\sigma}$	-	Equivalent stress.
σ_1, σ_2	-	Major and Minor true stresses,
σ_u	-	True tensile stress
σ_b	-	Tensile stress
e	-	Engineering strain.
$\bar{\varepsilon}$	-	Equivalent strain
ε_1 , ε_2	-	Major and Minor true strain.
ε_L	-	Equivalent limit localised strain
$d\varepsilon_1, d\varepsilon_2$	-	Strain increments.
$\varepsilon_1^*, \varepsilon_2^*$	-	Limit Strains
$d\varepsilon$	-	Effective strain increment.
ε_{1L} , ε_{2L}	-	Major and Minor instability limit strains
$d\lambda$	-	Constant.

The aim of the present work is to determine FLC using FLSC using the latest generalized yield equation developed by Narayanasamy et. al., [3] and Ponalagusamy et. al., [4]. Comparing the formability of the above (mentioned) three different steels.

3. Proposed Method of FLC Prediction from yield criteria

It will be very useful in computer modeling if the FLSC can be constructed from readily measurable material properties such as σ_u, n, k and r so that the FLCS can be drawn rapidly with less demand on experiments.

For plane – stress and an orthotropic and anisotropic material, the generalized yield criteria [2,3,6] for slightly compressible anisotropic metal is given by

$$f = \frac{\bar{\sigma}^2}{2\sigma_e^2} = \frac{1}{2\sigma_e^2}\left[\frac{2+R^N}{\left(2+r^p\right)\left(2+(p-1)^2 r^p\right)}\right]\left[|\sigma_1|^m + |\sigma_2|^m + r^p|\sigma_1 - \sigma_2|^m\right]^{2/m}$$

$$\left[\left[\frac{3}{2+r^p}\right]^{2/m}\frac{\left(1-R^N\right)}{3}|\sigma_1+\sigma_2|^2\right] \quad \ldots (1)$$

For this case, the corresponding equivalent strain is obtained as.

$$\bar{\varepsilon} = \left[\frac{X_1}{1+2^{m-1}\ r^p}\right]^{\left(1/m-1\right)} \left[|\varepsilon_1|^{\left(m/m-1\right)} + |\varepsilon_2|^{\left(m/m-1\right)}\right] + \left[\frac{X_1}{2}\right]^{\left(1/m-1\right)} \left[\left[1-\frac{1}{1+2^{m-1}\ r^p}\right]^{\left(1/m-1\right)}\right]\left[|\varepsilon_1 + \varepsilon_2|^{\left(m/m-1\right)}\right]^{\left(m-1/m\right)} \quad \ldots (2)$$

where X_1 = $\left[\frac{(2+r^p)\left[2+(p-1)^2\ r^p\right]}{2+R^N}\right]^{(m/2)}$

3.1. Local Instability

'f ' is the plastic function of the generalized yield criteria [1]. The expressions for the limit strains ε_1^* and ε_2^* can be obtained as.

$$\varepsilon_1^* = \frac{(X+Z)}{X+Y+2Z}\ .\ n \quad \ldots (3)$$

$$\varepsilon_2^* = \frac{(Y+Z)}{X+Y+2Z}\ .\ n \quad \ldots (4)$$

Where $X = \left(2+R^N\right)|\sigma_2|\left(2/m\right)\left[m|\alpha|^{m-1}+mr^p|\alpha-1|^{m-1}\right] \bullet \frac{K_1}{\left[\left(2+r^p\right)\left(2+(p-1)^2\ r^p\right)\right]}$

$Y = \left(2+R^N\right)|\sigma_2|\left(2/m\right)\left[m-mr^p|\alpha-1|^{m-1}\right] \bullet \frac{K_1}{\left[\left(2+r^p\right)\ \left(2+(p-1)^2\ r^p\right)\right]}$

and $Z = \left[\frac{3}{2+r^p}\right]^{2/m}\left(\frac{2}{3}\right)|\sigma_2|\left(1-R^N\right)|\alpha+1|$

where $K_1 = \left[1+|\alpha|^m + r^p\ |\alpha+1|^m\right]^{(2/m)-1}$

$\alpha = \left(\frac{\sigma_1}{\sigma_2}\right)$

after calculating the pairs of ε_1^* and ε_2^* for various α, one can represent the associated FLC.

3.2. Using the Levy – Mises Flow Rule to find the limit strains :

Using the Levy-Mises Flow rule for plastic deformation, when the stresses or stress-ratio $\left(\frac{\sigma_1}{\sigma_2}\right)$ is known, the corresponding strains can be found from the following relationship [10].

$$d\varepsilon ij = \frac{\partial f\,(\bar{\sigma})}{\partial \sigma ij} d\lambda \quad \ldots (5)$$

where $d\lambda = \dfrac{d\bar{\varepsilon}}{\left[\dfrac{df(\bar{\sigma})}{d\bar{\sigma}}\right]}$ ... (6)

The instability strain is given by

$$d\varepsilon_1 = \left[\frac{2 + R^N}{(2 + r^p)\left(2 + (p-1)^2 r^p\right)}\right] \bullet \left[|\sigma_1|^m + |\sigma_2|^m + r^p |\sigma_1 - \sigma_2|^m\right]^{\left(2/m - 1\right)}$$

$$\bullet \left[|\sigma_1|^{m-1} + r^p|\sigma_1 - \sigma_2|^{m-1}\right] + \left[\frac{3}{2+r^p}\right]^{2/m} \left[\frac{1-R^N}{3}\right]|\sigma_1 + \sigma_2|\Bigg]\frac{d\lambda}{\sigma_e^2} \quad \text{... (7)}$$

$$d\varepsilon_2 = \left[\frac{2+R^N}{(2+r^p)\left(2+(p-1)^2 r^p\right)}\right] \bullet \left[|\sigma_1|^m + |\sigma_2|^m + r^p|\sigma_1 - \sigma_2|^m\right]^{\left(2/m - 1\right)}$$

$$\bullet\left[|\sigma_2|^{m-1} - r^p|\sigma_1 - \sigma_2|^{m-1}\right] + \left[\frac{3}{2+r^p}\right]^{2/m} \left[\frac{1-R^N}{3}\right]|\sigma_1 + \sigma_2|\Bigg]\frac{d\lambda}{\sigma_e^2} \quad \text{... (8)}$$

where $d\lambda = \left[\dfrac{d\bar{\varepsilon}}{\bar{\sigma}}\right]\sigma_e^2$ ... (9)

and $K = \dfrac{\exp(n)}{n^n}(\sigma_b)$ ... (10)

The relationship between true tensile stress σ_u and tensile stress (σ_b) can be expressed as :

$\sigma_u = \sigma_b(1+e)$ ... (11)

In case of anisotropic material, the critical localized strain is given by.

$\varepsilon_{IL} = (1 + r^p)\, n$ ... (12)

The equivalent limit stress for uniaxial tension can be obtained as.

$\bar{\sigma}_L = K\left(\bar{\varepsilon}_L\right)^n$ ... (13)

Where $\bar{\varepsilon}_L$ is the equivalent limit – localized strain and is derived using equations (2) and (12).

3.3. Calculation of Limit Strains from Limit Stress

The forming limit stress curve (FLSC) can be obtained from the uniaxial localized necking stress state. First, the true tensile stress σ_u is calculated from equation (11) and the value of K is calculated from (10). The uniaxial theoretical localized instability strain can be obtained using equation (12). From the result of equation (12), the equivalent limit stress at the localized neck is determined from equation (13).

From single limit yield stress, the FLSC can be determined by using the yield criterion equation (1). Since the FLSC is non-linear (or not a straight line), the linear regression method can be used to obtain the FLSC as a straight line. The equivalent stress corresponding to each point on the FLSC can be determined using equation (1) and the equivalent strain can be obtained using equation (2). Assuming a liner strain path, one can obtain the principal major and minor stains using equations (7), (8) and (9).

4. Results and Discussion

4.1. Forming Limit Stress Curve

The proposed method for predicting the forming limit curves has been tried out with generalized yield equation, by using the experimental values of σ_u, r and K that are available in the literature [5]. The tensile test data obtained for the present work is shown in Table (1). Mechanical properties of Steels for different grades are given in Table (2).

In Fig (1) the linear and non-linear forming limit stress curves (FLSC) of IF steel SS430 and EDDQ are given. It is observed that for a given value of minor principal stress, the major principal stress increases for m = 3, p = 1, R = 1 and N = 2. For the given value of minor principal stress, the major principal stress increases more for IF steel compared to other steels SS430 & EDDQ.

Further from Fig (2) the rate of increase or decrease in the variation of the major principal stress with the minor principal stress becomes predominant for IF steel.The foregoing characteristic may be attributed to the change in the shape of yield locus. It shows the better formability of IF steel.

Figure 1 : Non-Linear and Linear FLSC

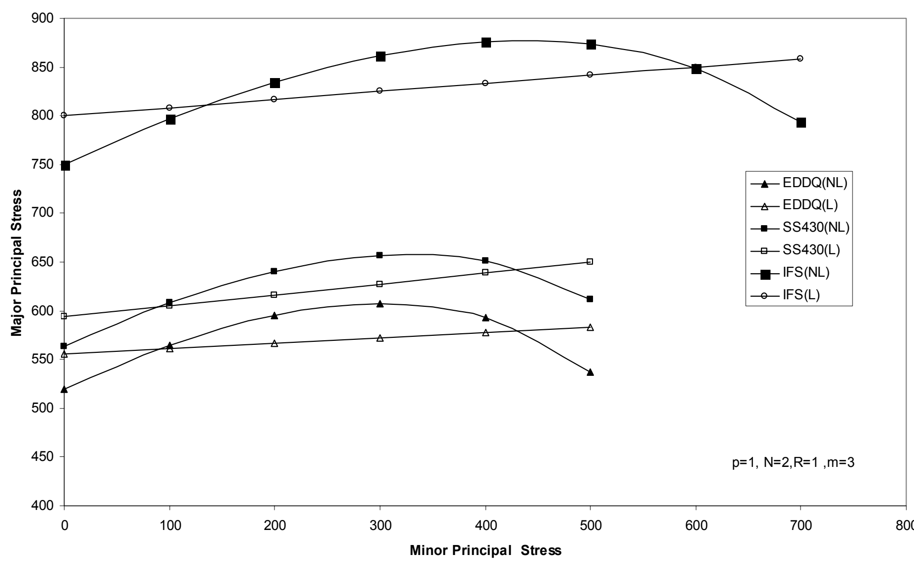
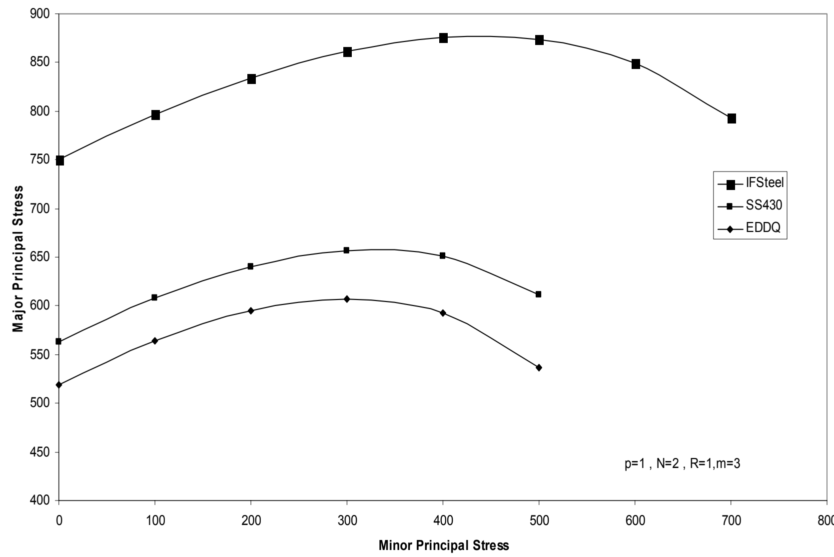


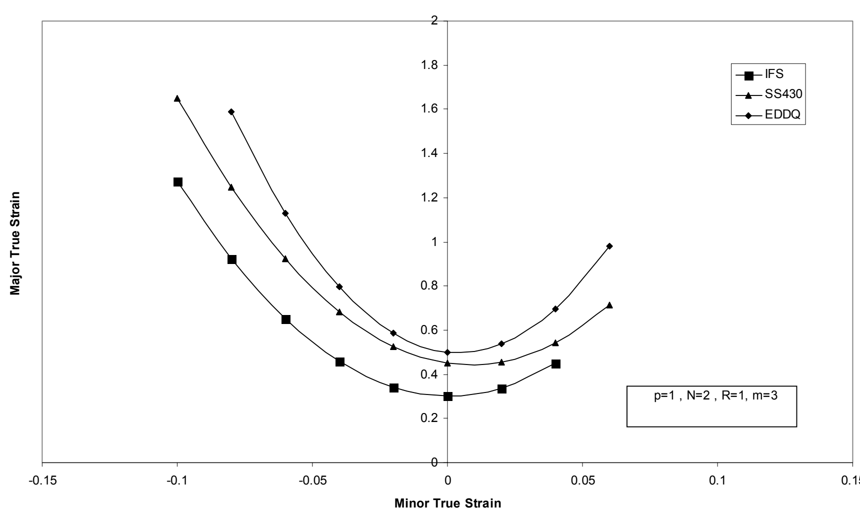
Figure 2 : FLSC



4.2. Forming Limit Curve

The attention of the present investigation is also focused on the Formability on forming limit curve (FLC) or forming limit diagram (FLD) for the three steels Fig (3). For a given value of minor true strain ,the major true strain decreases for the value of m=3. FLC becomes predominant when the value of minor true strain is negative but it is less predominant as the value of minor true strain is positive .It is of interest to mention that IF steel has better formability compared to SS430 & EDDQ .

Figure 3 : FLC



5. Conclusion

The formability of three steels (IF steel, SS430, EDDQ) are analysed theoretically and compared by taking the value of the parameters as m=3,p=1,R=1 and N=2. IF steel has better formability than other two steels namely SS430 and EDDQ.

Table 2 : Mechanical properties of various steels used for verifying the new methodology for obtaining the FLCs.

STEELS	K Mpa	$\bar{\sigma}_L$ Mpa	R	p	r	n	N	M
1. IF - Steel	578	572	1	1	2.09	0.32	2	3
2. SS 430	589	496	1	1	1.06	0.228	2	3
3. EDDQ – Steel.	480	418	1	1	1.67	0.141	2	3

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