

# Transformation of localized necking of strain space into stress space for advanced high strength steel sheet

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**Abstract.** Normally, Forming Limit Curves (FLCs) can't explain for shear fracture better than Damage Curve, this article aims to show the experimental of Forming Limit Curve (FLC) for Advanced High Strength Steel (AHSS) sheets grade JAC780Y with the Nakazima forming test and tensile tests of different sample geometries. From these results, the Forming Limit Curve (strain space) was transformed to damage curve (stress space) between plastic strain and stress triaxiality. Therefore, Stress space transformed using by Hill-48 and von-Mises yield function. This article shows that two of these yield criterions can use in the transformation.

## 1. Introduction

In recent years, the automotive industry focusses on energy savings. Advanced High Strength Steel (AHSS) is a crucial demand for the automotive industry and trend to increase caused by lightweight steels. The main defects of sheet metal forming in automotive industry is fracture caused by necking [1] forming limit curve (FLC) of sheet metals is popularly employed in automotive industries. Nevertheless, the behavior of advanced high strength steel (AHSS) grades with decreased ductility develop an issue concerning shear fracture. This issue could not be accurately predicted by the conventional forming limit curve (FLC). With this procession, the new forming criterion is cultivated, for example; the new representation of damage curve with relates to stress space between plastic strain and triaxiality [2]. In this work, studied in strain space by using the test of Nakajima test and tensile tests of pure shear and combined loading specimens of Advanced High Strength Steel (AHSS) grade JAC780Y. Afterwards, analysis in transformation's calculated of forming limit curve (strain space) to be damage curve (stress space) by using anisotropic Hill-48 yield function and isotropic von-Mises yield function.

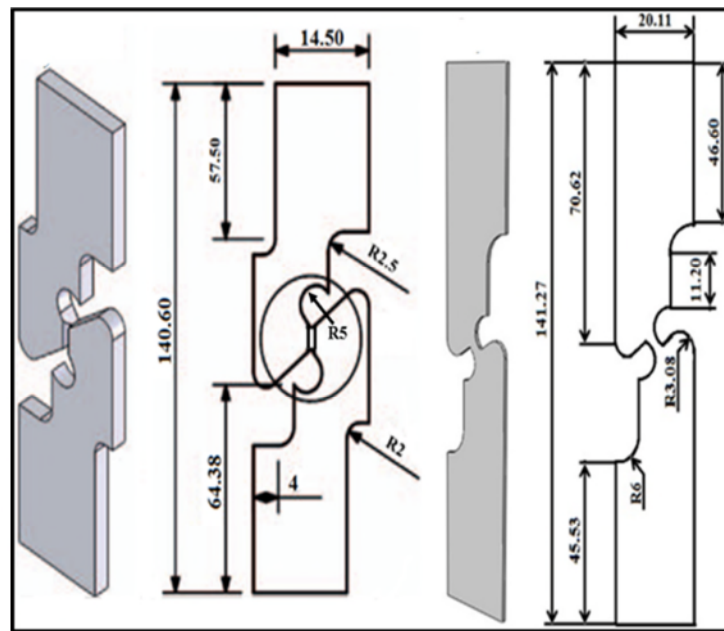
## 2. Measurement of strain based forming limit curve

### 2.1. Nakajima test

The experimental forming limit data for JAC780Y advanced high strength steel (AHSS) sheets was obtained from the Nakajima test which accomplished by make use of the standard ISO 120004 - 2 [1, 2] and each samples repeated three times. All of the sheet samples' shape had 200 mm of length. However, the widths were varying between 55 to 200 mm. The thickness of the steel sheet was 1 mm. In this the experiments, the mean of an optical strain measurement system accumulated the mutilated samples' local strain histories. Generally, the evaluation of critical plastic strains for regular FLC occurred from estimated strain distributions at the stage of localized necking. This stage of localized necking could be characterized by local strain rates' development. In this case, the maximum rate of



thickness reduction of principal in plane plastic strains were classified. Afterward, it's used as limiting strain values to fracture for the FLC (strain based).



**Figure 1.** Pure shear/combined load sample [4].

## 2.2. Shear fracture limit test

Pure shear's tensile tests and combines loading specimens were carried out for the receiving fracture beginning strains due to shear failure statue. Figure 1 show geometries of pure shear's using and combined loading sample [4]. In pure shear sample's case, the middle area of the sheet sample was controlled by closely pure shear stress. For the combined loading sample, the pure shear sample was lightly altered to produce a stress state revealing a combination of shear and tensile loading, as shown by Bao and Wierzbicki. [5]. The optical strain measurement system was also involved in experiment of calculation of local strain distributions developing in the critical field of both cases. Comparable with Nakazima test, the analytical maximum and minimum in level strains were obtained at the stage before crack appearance and used as shear fracture limit strains.

## 3. Measurement of stress based damage curve

### 3.1. Uniaxial tensile test

The ASTM E8 standard specimen was used in uniaxial tensile test of the investigation of steel sheet activity. The test of sheet sample went through three loading directions; 0°, 45° and 90°. These directions became the rolling direction (RD). In the tension test, elongations within the gauge length of the test specimens regarding both sample length and width were determined. The calculation of  $r$ -values was undergoing by the ratio between valid width and thickness measured up to 15% of the total elongation.

### 3.2. Transformation into stress space damage curve

Obtainable forming limit strains were transformed into stress triaxiality and plastic strain space under condition of anisotropic Hill'48 yield function and isotropic Von-Mises yield function [5]. The strain ratio ( $\alpha$ ) was defined by  $\alpha = (\epsilon_2 / \epsilon_1)$  and the average normal anisotropy was expressed as  $\bar{r} = (r_0 + 2r_{45} + r_{90})/4$ . The maximum and minimum principle strains could be transformed to

stress triaxiality ( $\eta_{Hill'48}$ ) and effective plastic strain ( $\bar{\varepsilon}_{Hill'48}$ ) space combined with Von-Mises yield function by equation 1 and 2, with Hill'48 yield function by equation 3 and 4 [5].

$$\eta_{iso} = \frac{1 + \alpha}{\sqrt{3}\sqrt{1 + \alpha + \alpha^2}} \quad (1)$$

$$\bar{\varepsilon} = \frac{2\varepsilon_1}{\sqrt{3}} \sqrt{1 + \alpha + \alpha^2} \quad (2)$$

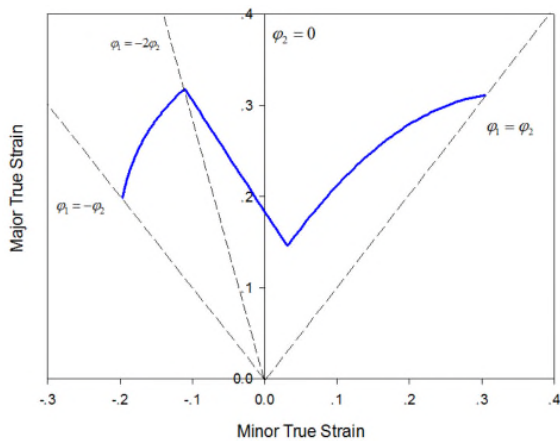
$$\eta_{Hill'48} = \left( \frac{\sqrt{1 + 2\bar{r}}}{3} \right) \times \frac{1 + \alpha}{\sqrt{1 + \left[ \frac{2\bar{r}}{1 + \bar{r}} \alpha \right] + \alpha^2}} \quad (3)$$

$$\bar{\varepsilon}_{Hill'48} = \frac{1 + \bar{r}}{\sqrt{(1 + 2\bar{r})}} \sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \frac{2\bar{r}}{(1 + \bar{r})} (\varepsilon_1 \varepsilon_2)} \quad (4)$$

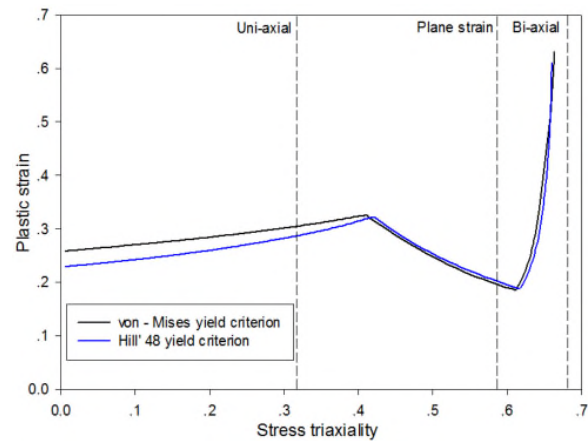
## 4. Results and discussion

### 4.1. Forming limit curve in strain space

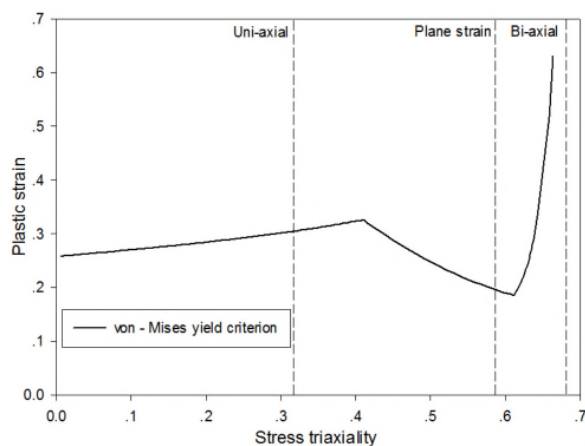
In the figure 2 show that in the Nakajima test and tensile test of shear and combined loading specimen, the determination was seen in the forming limit curve (strain based) of the examined steel grade JAC780Y. The strain based forming limit comprised three strain divisions. The first division correlated to the stress states between biaxial tension ( $\varphi_1 = \varphi_2$ ) and plane strain ( $\varphi_2 = 0$ ). The second domain was the scope from planes strain ( $\varphi_2=0$ ) to uniaxial tension ( $\varphi_1 = -2\varphi_2$ ). The last division showed the stress state from uniaxial tension ( $\varphi_1 = -2\varphi_2$ ) to pure shear ( $\varphi_1 = -\varphi_2$ ). This third strain domain represented the shear failure of the steel's limit.



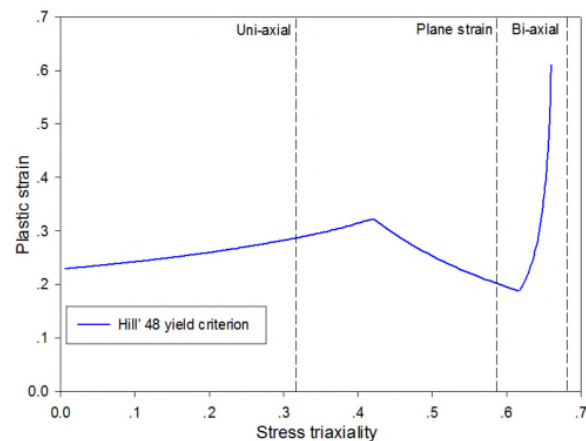
**Figure 2.** Forming limit curve (strain base) of JAC780Y steel.



**Figure 3.** Damage curve of JAC780Y steel von-Mises and Hill'48 yield criterion.



**Figure 4.** Damage curve of JAC780Y steel with von-Mises yield criterion.



**Figure 5.** Damage curve of JAC780Y steel with Hill'48 yield criterion.

#### 4.2. Calculation of damage curve in the stress space

The stress triaxiality and effective plastic strain space by numerical calculations came from the transformation of the strain based forming limit curve in figure 3. According to equation 1 and 2 for von-Mises yield criterion was displayed in figure 4 and equation 3 and 4 for Hill' 48 yield criterion in figure 5. At the same time, the stress based damage curve presented three separate divisions. The strain based forming limit curve show that the three areas correlated to the equal states of stress. Notice that the pure shear state, biaxial tension, plane strain and uniaxial tension were approximately showed by the triaxiality values of 0.667, 0.575, 0.33 and 0. In the section of pure shear - uni-axial tension hill'48 yield criterion was under the von - Mises yield criterion. As well as uni-axial tension - plane strain Hill'48 yield criterion was upper than von - Mises yield criterion along with plastic strain's axis. The beginning of section of plane strain - Bi-axial, von - Mises yield criterion had stress triaxiality's value below than hill'48 yield criterion. The end of the Hill'48 yield criterion had stress triaxiality's value was below von - Mises yield criterion along with the Stress triaxiality's axis.

### 5. Conclusion

The current results show the strain and stress based damage curves from the AHS steel grade JAC780Y. The Nakajima test and tensile tests of pure shear and combined loading specimens were operated for receiving the forming limit curve. At that point, the strain based forming limit curve was converted to damage curve relationship of stress triaxiality and effective strain space under examined of the Hill'48 and von-Mises yield function. In future work, this damage curve relationship of stress triaxiality and plastic strain space will have examined on the geometries of automotive industry parts.

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