Determination of Forming Limit Diagram (FLD) by Using Tensile Testing Machine

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Abstract

Forming limit diagram (FLD) has been wildly used to evaluate the formability of sheet metal. This FLD could be determined by several methods. Tensile test was one of the several methods that useful to evaluate FLD. This test could be determine by using the available machine, such as Instron, and did not have the influence of friction between specimen and machine. This paper focuses on the study of FLD by using tensile testing machine. The effect of rolling direction of material on forming limit curve (FLC) was also investigated. The specimen was made of the sheet metal grade JSC 270D which had the wall thickness 1.2 mm. The tests would be conducted by considering of three different rolling directions namely rolling direction (RD), diagonal direction (DD) and transverse direction. The strain states were varied by the different radius of specimen. In order to obtain the strain, major strain and minor strain, and ensure the assumption of linear strain path, AutoGrid® compact device was carried out during the tests. This procedure could be constructed the left-hand side of the forming limit curve (FLC) and could be shown the effect of rolling direction on FLC.

***Keywords**:* Forming limit diagram (FLD), JSC 270D, tensile testing, strain measurement, AutoGrid® compact.

1. Introduction

Sheet metal was one of the commonly semi-finished products used in many applications such as food container, automobile industries etc.

In the production process, the structure usually combined with complex shapes, which were achieved by sheet metal. According to the deformation of sheet metal into the required shape, the increasing of deformation made the risk of necking follow by ductile fracture, which was a common failure mechanism in sheet metal structure [1-3].

In order to evaluate the formability of sheet metal before real processing, forming limit diagram (FLD) has been widely used as one of the technique for optimizing and correcting problems in line production as stamping processes and the design of dies especially in the car industry.

The concept of FLD introduced by Keeler and Goodwin [4]. The FLD was represented by the relationship between major strain and minor strain at the onset of local necking [5]. The local necking is the form of necking that lead to fracture. At first in sheet specimens, the specimen elongates uniformly. At maximum load a diffuse neck form by contraction of both width and thickness and finally local neck develop. The drawing of diffuse necking and local necking in sheet sample was shown in Fig.1.

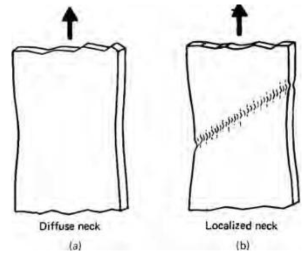


Fig.1. (a) diffuse necking and (b) local necking in sheet sample [4]

According to the assumption of linear strain path of FLD, each strain path could be descripted through the parameter ρ representative of the strain state and given by Eqs. (1).

$$\rho = \varepsilon_2 / \varepsilon_1 \qquad (1)$$

The different strains in the sheet plane are illustrated, ε_1 is defined as the major and ε_2 is the minor strain. The thickness strain ε_3 can be determined by the law of constancy volume.

Fig. 2 shows the four characteristic forming state, which can be distinguished in sheet metal forming. State 1: $\varepsilon_1 = -\ \varepsilon_2$ deep drawing, state 2: $\varepsilon_1 = -2\varepsilon_2$ uniaxial tension, state 3: $\varepsilon_1 = 0$ plane strain and state 4: $\varepsilon_1 = \varepsilon_2$ biaxial stretching [1-2].

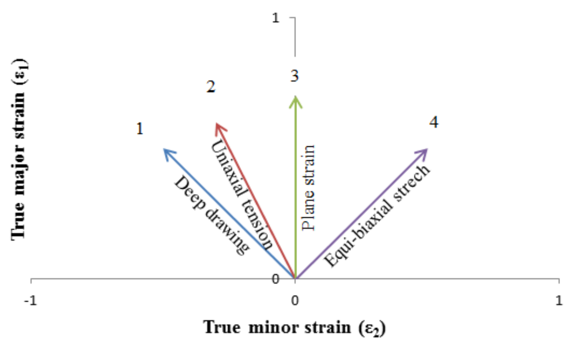


Fig.2. Forming state in sheet forming [1]

The commonly techniques that used to determine the FLD of sheet metal is hemispherical punch method by using the forming from hemispherical punch on sheet specimens which were simulated the strain state by varying width and curve radius of specimen such as Erichsen test, Olsen test and limit dome height test (LDH). [6-10]

According to hemispherical punch method used the specific machine. Therefore, the more available tensile testing machine becomes an alternatively machine used to determine the FLD. Thus this paper is interested in the ability of tensile testing machine to construct the forming limit diagram (FLD) by using JSC 270D as the sheet specimens to study because of a widely used material for the part of automobile application. Moreover, this study also has investigated the influence of the rolling directions to the formability of this sheet metal.

2. Experimental procedure

2.1 Chemical composition and mechanical properties

According to the outstanding of good properties and widely used in automobile, the cold rolled sheet metal grade JSC 270D with 1.2 mm thickness was selected to use in this study.

An optical emission spectrometer (Thermo electron, Model 3460, USA) was used to analyze the chemical composition of this sheet metal. The chemical composition was shown in Table.1.

Table. 1 Chemical composition, %

Symbol of grade	C%	Si%	Mn%	P%	S%	Cr%
JSC270D	0.0053	0.0089	0.1370	0.0191	0.0037	0.0554

The mechanical properties were shown in Table. 2. The universal tensile testing machine (Instron, Model 5569, USA) with a maximum tensile force capacity of 50 kN was used to determine properties of this metal on three directions of rolling on sheet metal.

Table. 2 Mechanical properties of JSC 270D on each direction of rolling

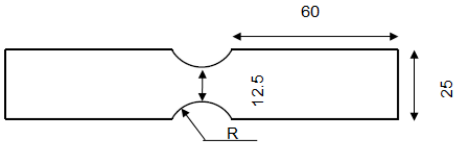
Direction of rolling	Plastic stain ratio (r-Value)	Strain-hardening exponent (n-Value)	Strength coefficient (K-Value)	Yield strength (MPa)	Tensile strength (MPa)
RD (0°)	2.124	0.235	564	168	319
DD (45°)	2.363	0.233	565	173	321
TD (90°)	3.259	0.230	555	172	314

*RD=Rolling Direction, DD=Diagonal Direction and TD=Transverse Direction

2.2 Forming limit diagram by using tensile testing machine

To avoid the effect of heat affected zone on the edge of specimen the water jet cutting was selected to cut all of specimens in this experiment.

The specimens were prepared by cutting into rectangular shape along three different directions namely rolling direction (RD), diagonal direction (DD) and transverse direction (RD). A schematic drawing of specimen was show in Fig.3. The 25 mm of width was determined to be equal to the size of wedge grip. The specimens were provided notch in order to receive a well-defined necking region at the middle of specimen. In order to obtain different strain paths the different curve radius of specimens were varied.



Specimen	1	2	3	4
Radius (R)	3.125	6.25	12.5	25

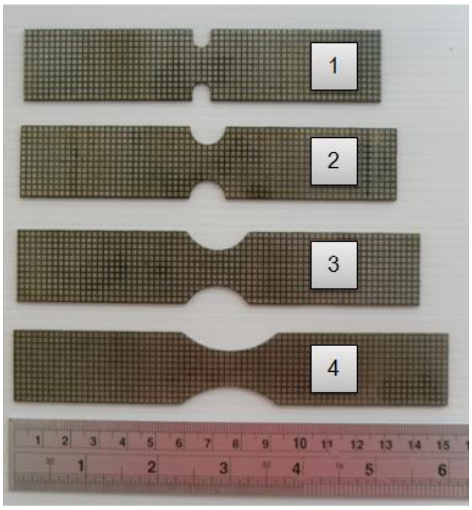


Fig. 3 Schematic drawing of specimen geometry used in the tests

In order to determine the FLD of JSC 270 D before testing, all of the specimens were made the square grid pattern with size 2 mm x 2 mm on surface by using electrochemical etching equipment [11].

The universal tensile testing machine was carried out at room temperature. The specimen was gripped at the grip section with 1 cm of distance from notch of specimen in order to take the photo of the specimen. The tests were run in deformation control with crosshead speed 0.5 mm/min. During the test, the camera of AutoGrid® strain analysis system (Vialux, Model AutoGrid® compact, German) was used to take the photo of specimen by setting the focus of camera directly to the specimen. The photos were taken continuously. The photos of square grid changing that receive from the camera were analysis by AutoGrid® program on the computer and showed the output of true strain (ε_1, ε_2 and ε_3). The coordinates of true major strain (ε_1) and true minor (ε_1) were plotted in the graph from uniform elongation deformation until necking onset occurred. The schematic drawing of experiment set up was shown in Fig. 4.

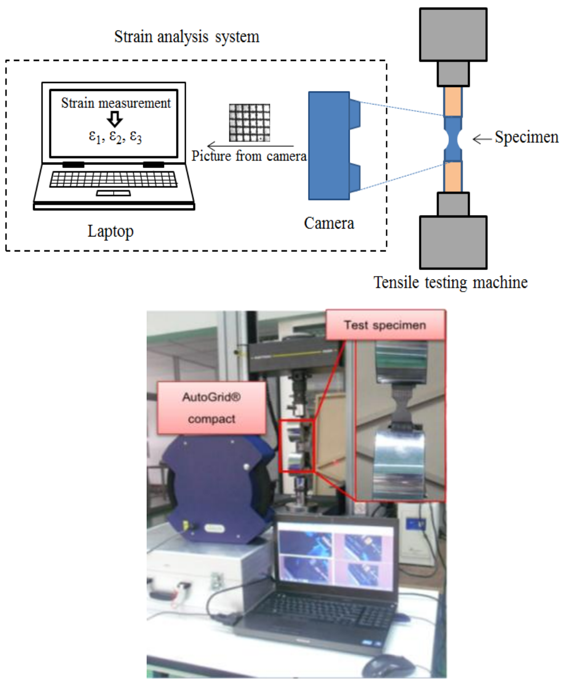


Fig. 4 Schematic drawing of experimental set up

3. Result

From the experiment, the analysis of strain via AutoGrid® compact device was shown in Fig. 5. After deformation by tensile testing machine, the specimens with grid pattern were calculated the strain from point measurement and were shown the result of true strain in contour picture. At the center of specimen showed the significantly different of color from both sides.

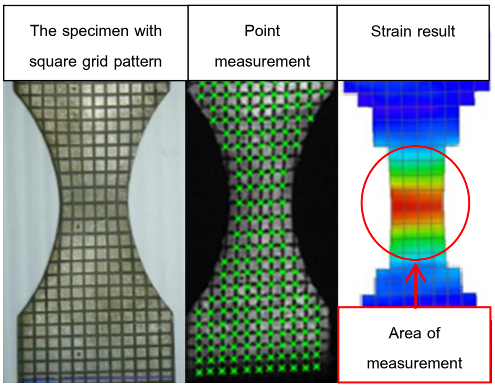
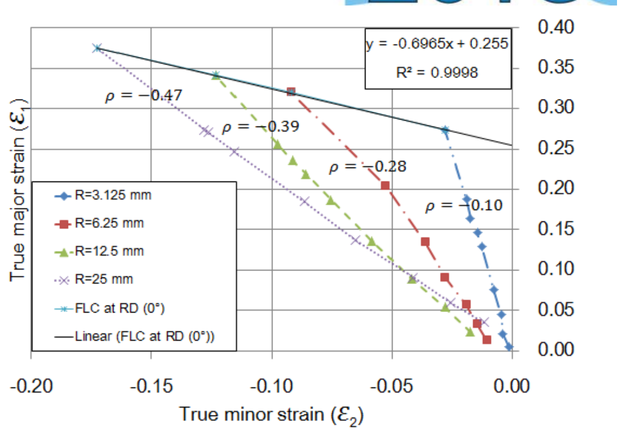


Fig. 5 The evaluation of strain from AutoGrid® compact device

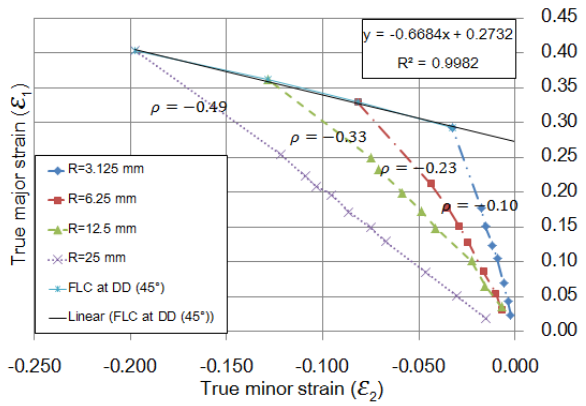
The major strain and minor strain were collected and plotted into the graph as a coordinate of true strain as showed in Fig.6.

From Fig.6, this experiment procedure could be used to determine FLC on the left hand side of FLD. Each step of forming, all of specimens gave constant trend of linear strain ratio. The different radius of specimens provided the different strain ratio, -0.47 to -0.10 at rolling direction, -0.49 to -0.10 at diagonal direction and -0.51 to -0.11 at transverse direction. The large radius of specimen curve provided the strain ratio close to uniaxial tension and the smaller radius provided the strain ratio close to plane strain.

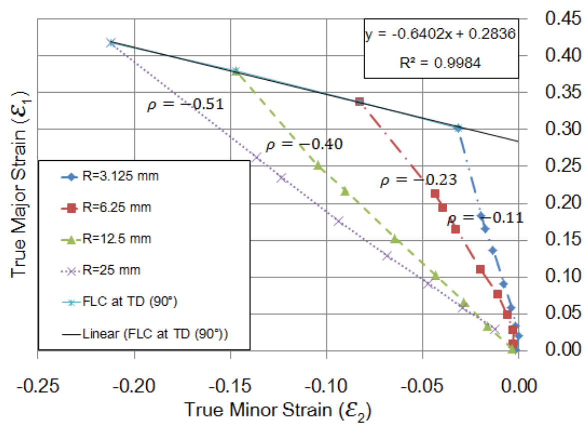
At localized necking, the connection between 4 limit strain values from 4 different specimen geometries had linear trend relation. The drawing of the linear trend line could use to roughly approximate the limit strain at plane strain.



(a)



(b)



(c)

Fig.6 The forming limit diagram of JSC 270D with 25 mm, 12.5 mm 6.25 mm and 3.125 mm of specimen radius at (a) rolling direction, (b) diagonal direction and (c) transverse direction

From the trend lines of FLC, the forming limit strain details were shown in Table. 3. At plane strain condition, the specimen at transverse direction provided the highest strain value, and the specimen at rolling direction provided lowest strain value.

Table. 3 Details of forming limit strain

Direction of rolling	Tension-compression strain condition		Plane strain condition
	True major strain	True minor strain	True major strain
RD (0°)	0.375	-0.173	0.255
DD (45°)	0.404	-0.198	0.273
TD (90°)	0.417	-0.212	0.283

Fig. 7, at rolling direction, the FLC between JSC 270D from this experiment and sheet metal with the close properties from the hemispherical punch method was compared.

In this case, the FLC of IF steel from the experiment of the hemispherical punch method by R. Narayanasamy [12] was selected. The result from comparing showed the FLC of IF steel from the hemispherical punch procedure has higher line than FLC of JSC 270D. At plane strain IF steel has the limit strain above JSC 270D around 8%. Which is a sequel of friction as it can be seen from research by M.M. Moshksar [13] found the influence of friction between specimen surfaces and dies regarded to the FLC by retarding the onset of the local strain. In this test used tensile testing. The specimens have not touched on the machine. Then the friction was neglected.

The comparison between 3 rolling directions, FLC at transverse direction has slightly more strain value of FLC than the others. FLCs between rolling direction and diagonal direction have the close value of strain. The FLCs has corresponding with R- value. The higher R-value provided higher strain than the lower R-value.

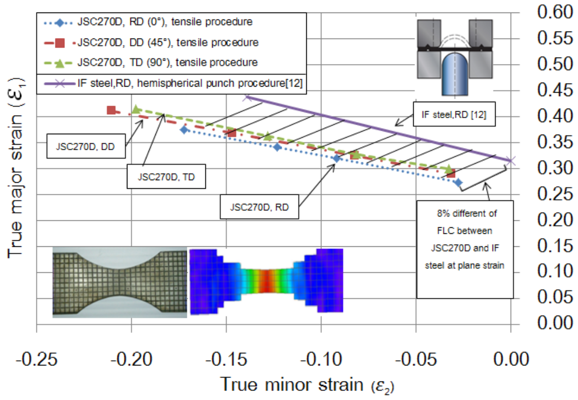


Fig.7 The comparison of FLD between rolling direction (RD), diagonal direction (DD) and transverse direction (TD)

4. Conclusion

Tensile testing machine could be used to determine FLD of JSC 270D. By changing of the specimen geometries, the coordinate of major strain and minor strain could be constructed the left-hand side of FLC with liner strain path. The radius of notch on specimen has large influence on the strain state. The strain ratio from this experiment occurred between uniaxial tension and plane strain. The smaller radius provided the strain ratio close to plane strain. For this sheet metal, the direction of rolling has small effect. It has slightly different between three directions of FLCs. At rolling direction, the FLC of JSC 270D from tensile procedure has been lower than IF steel from conventional procedure approximately 8%.

5. Acknowledgement

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6. Reference

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