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Forming Limit Prediction of High Tensile Strength Steel using FEA Simulation

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Abstract:-Forming limit prediction of High Tensile Strength Steel (HTSS) sheet was carried out by using finite element analysis. JSTAMP/NV was used in the finite element analysis. Thickness of HTSS specimen was 1.0mm, and the length was 120mm.And the width was varied from 20mm to 80mm. Stretching test was operated by Erichsen test. In this study, the forming limit prediction method for predicting the localized necking before the fracture was proposed.FLD of HTSS was compared between experimental results and analytical results. Forming limit diagrams (FLD) obtained by FEAagreed well with the FLD obtained by experiment.

Keywords:-Finite Element Analysis, Sheet Metal, High Tensile Strength Steel, Forming Limit Diagram, FLD

I. INTRODUCTION

Recently, the demands for weight saving technology and improving collision safety have been increasing in automotive industry. Especially, it is said that reducing the automotive weight 100 kg improves the fuel consumption 1 km/l. And it is able to reduce the CO_2 emissions that causes global warming. However, weight saving of automotive generally causes decreasing collision safety. Thus, high tensile strength steels (HTSS) are expected as substitute of common steelsbecause HTSS has high specific strength compared with common steels.Though, it is difficult for HTSS to apply to complicated shapes, because of poor cold formability due to the high strength. The precise estimation method for press formability is necessary for expansion of HTSS application.Forming Limit Diagram (FLD) is one of standards indicating the formability of sheet metal.It is required that better accuracy of the forming limit prediction, and comparative evaluation of experiment and finite element method is carried out by many researchers [1]. Generally, a ductile fracture criterion is used to calculate a FLD by finite element method, it is problem that ductile fracture is instability phenomenon. Especially, the accuracy of prediction of forming limit on biaxial tensile area is poor. In this study, the forming limit prediction method for predicting the localized necking before the fracture was proposed. The advantage of this method is easy estimable method for forming limit comparing to other methods that is using the forming limit as a ductile fracture criterion. FLD of HTSS was obtained by stretching test experiment and finite element analysis. An obtained FLD was compared to find an exact point of fracture between experimental values and analytical values. It was found that the proposed method using finite element analysis for obtaining FLD was effective for prediction of a necking occurrence while forming of HTSS sheets.

II. EXPERIMENT

A. Erichsen Test

Erichsen testing machine, ERICHSEN GmbH & Co. KG, model 142-20, is shown in Fig. 1. Fig. 2 shows an example specimens of stretching test in this study. Erichsen testing machine was used to measure the centerheight of stretched specimen. The punch diameter was 50mm. Maximum blank-hold force was 100 kN.Teflon sheet was used for low friction lubricant between specimen and dies. Table 1 shows the specifications of Erichsen testing machine. Grid marking was stamped to the specimen, and the deformation of the grid was observed with four cameras.The strain was obtained by measuring the deformation of the grid with the three-dimensional measuring machine during the test.The strain ratio and the strain path was obtained by changing the width of the specimen. The used three-dimensional measuring machine was ViALUX, Auto Grid. Table 2 shows the specifications of three-dimensional measuring machine.

Fig. 1:Erichsen testing machine and measuring cameras

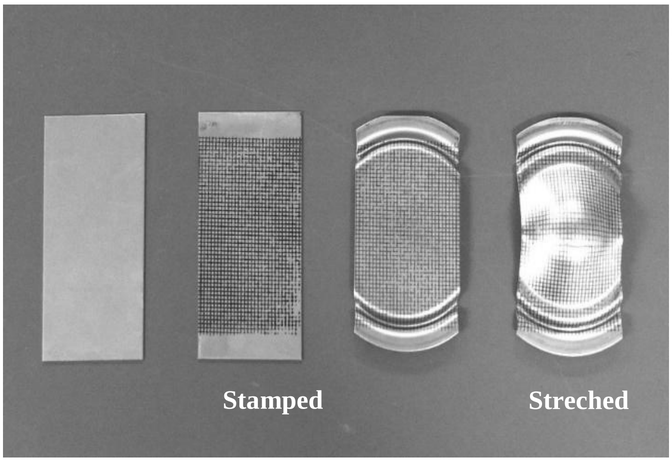

Fig. 2:Specimens of stretching test

Table 1: Specifications of the Erichsen Testing Machine

Machine model	142-20
Manufacturer	Erichsen
Diameter of Punch [mm]	50
Blank Holding Force [kN]	100

Table 2: Specifications of the Three-dimensional Measuring Machine

Machine Model	AutoGrid
Manufacturer	ViALUX
Measuring Area $x{\times}y{\times}z$ [mm]	500×500×200

B. Test Material

In this study, 980MPa class high tensile strength steel sheet was used. Table 3 shows the material properties of 980MPa class HTSS. Specimen length was 120mm, and the thickness was 1.0mm. Specimen widths were 20mm, 40mm, 60mm and 80mm, respectively. The elongation of this material after necking was littlein uniaxial tensile test.

Table 3:Material Properties of 980 MPa Class High Tensile Strength Steel

Tensile strength	[MPa]	1018
Yield stress	[MPa]	644
Elongation	%	18
Poisson's ratio		0.30
***K*-value**		1522
***r*-value**	Average 0° 45° 90°	0.83 0.81 0.87 0.77
***n*-value**		0.12

C. Forming Limit Diagram

Forming limit diagram (FLD) of 980MPa class HTSS sheet obtained by experiment is shown in Fig.3 and Fig. 4. Fig. 3 shows the conventional fracture FLD, and Fig. 4 shows the Necking FLD. The distributions of the fracture and necking strains obtained from uniaxial tensile side to plane tensile side were the linear downward-sloping. And the distributions of the fracture and necking strains obtained from plane tensile side to biaxial tensile side were the linear upward-sloping. Necking strains were distributed under the fracture strain distributions. In this study, it was defined that the localized necking occurred when the difference of thickness reduction rate between adjacent grid strains was reached up to 5 %.

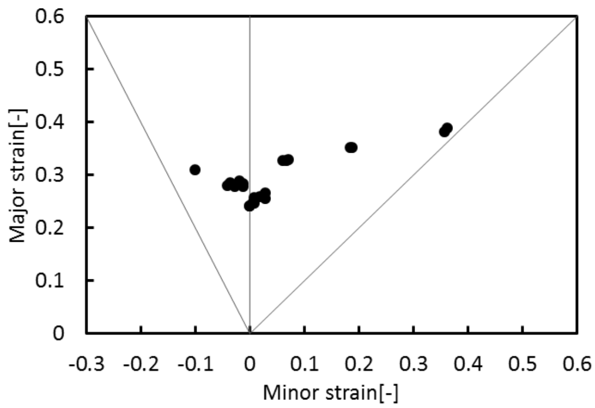

Fig. 3:Experimental FLD (Fracture)

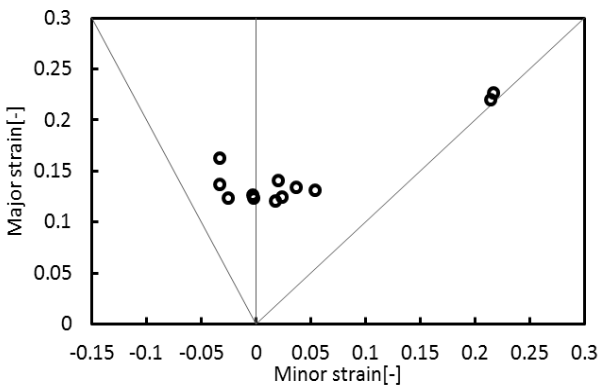

Fig. 4:Experimental FLD (Necking)

III. FINITE ELEMENT ANALYSIS

Analytical Erichsen test was operated by using finite element method. Analysis software is from JSOL, JSTAMP/NV. Element size was 1mm × 1mm, and the element type was shell type with 5 integration point in the thickness direction. Friction coefficient was 0.05 between blank and punch, and was 0.15 between blank and top die respectively. Stress strain curve was approximated with Swift's formula. Analytical model was applied quarter model considering the symmetry. The model was constructed by simple shaped die in order to eliminate the effect of blank vibrations caused by blank holding. FEM analysis was operated stretching process only. Instead of the blank hold process, node restraint was adopted. Yield function Hill'48was applied. Fig. 5 to Fig. 7 show the analytical model. In this paper, a ductile fracture criterion was applied for the prediction of necking occurrence at uniaxial tensile side. Ata biaxial tensile side, the localized necking occurrence was evaluated by using the change of thickness reduction rate between adjacent element same as experiment.

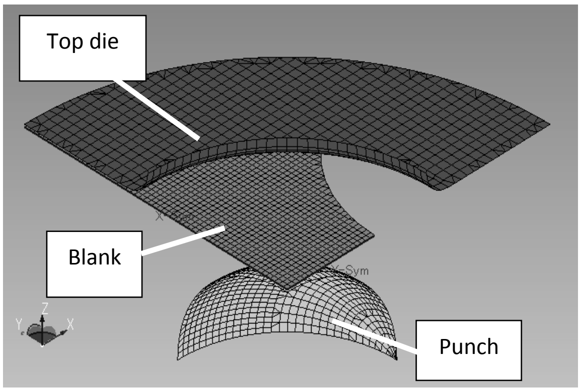

Fig. 5:Analytical Model

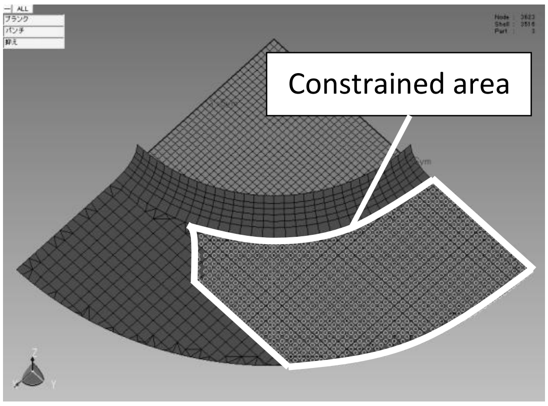

Fig. 6:Analytical Model and Restrained Nodes (From Upside)

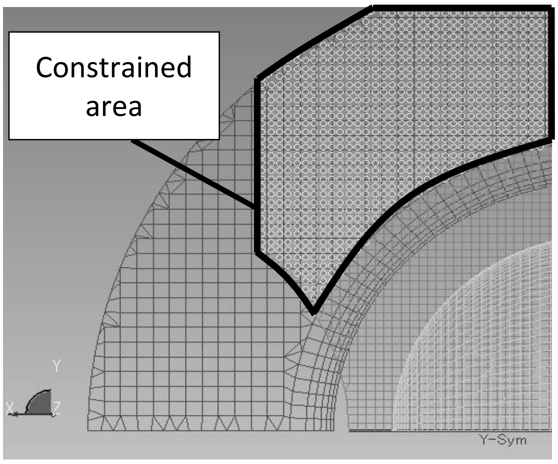

Fig. 7:Analytical Model and Restrained Nodes (From Reverse Side)

IV. DUCTILE FRACTURE CRITERION

Ductile fracture criteria expresses the stress and strain state at fracture. In this study, the localized necking at uniaxial tensile side was predicted by applying Cockcroft – Latham's ductile fracture criterion; (1)

$$\int_0^{\bar{\varepsilon}_N} \sigma_{max}\, d\bar{\varepsilon} = C \qquad (1)$$

where, $\bar{\varepsilon}_N$ is equivalent strain of necking, σ_{max} is max principal stress, $d\bar{\varepsilon}$ is increment of effective strain, and C is material constant. In addition, σ_{max} is expressed the relation (2) in tensile state [2].

$$\sigma_{max} = \sigma_m + \frac{2}{3}Y \quad (2)$$

where, σ_m is mean normal stress, and Y is yield stress. In this paper, 127 is used as the C value from the result of tensile test.

V. ANALYSIS RESULTS AND DISCUSSION

FLD comparison between experimental results and analytical results is shown in Fig. 8. The ductile fracture criterion was applied in the analytical FLD at the uniaxial tensile side (plots of FEM-1). The change of thickness reduction rate was used as a reference of necking occurrence same as the experiment in the biaxial tensile side (plots of FEM-2). Analytical FLD agreed well with experimental FLD. In the case of applying only a ductile fracture criterion in the biaxial tensile side, forming limit was underestimated. It is supposed that the highly accurate forming limit is obtained to apply the appropriate change of thickness reduction rate at from plane strain deformation area to biaxial tensile area.

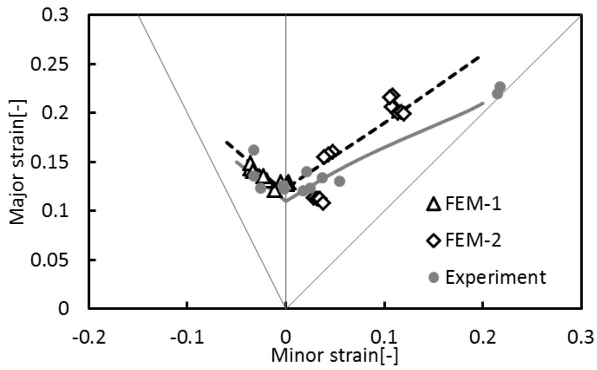

Fig. 8:Comparison between Analytical Results and Experimental Results

VI. CONSLUSION

Forming limit diagram (FLD) of 980MPa class high tensile strength steel sheet (HTSS) was obtained by Erichsen stretching test and finite element method. JSTAMP/NV was used in the finite element analysis. The Cockcroft – Latham's ductile fracture criterion was applied for the prediction of localized necking in the uniaxial tensile state, and the change of thickness reduction rate was used as a reference for localized necking occurrence in the biaxial tensile state. Analytical FLD agreed well with experimental FLD.

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