Measurement of local necking in tensile test of mild steel sheet for forming numerical simulation

D Shimizu, S Takahashi, H Sunaga, M Takamura, S Mihara, E Oohashi

1 College of Industrial Technology, Department of Mechanical Engineering, Nihon University, 1-2-1 Izumi-cho, Narashino, Chiba, 275-8575, Japan
2 Center for Advanced Photonics, RIKEN, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan
3 DV Div., FASOTEC Co., Ltd, 1-3 Nakase, Mihama-ku, Chiba, 261-8501 Japan

cida17016@g.nihon-u.ac.jp
takahashi.susumu32@nihon-u.ac.jp
sunaga@riken.jp
takamura@riken.jp
smihara@riken.jp
oohashi@fasotec.co.jp

Abstract. Plate forging can be applied to the reduction of the forming time and costs of parts which have large thickness and complex shape. In many cases, the surface quality of the shearing portions is very important when their surfaces slide along those of other parts. The research and development of analytical methods for evaluating the surface condition of shear deformed parts are underway. Fracture in plastic working is generally ductile fracture. Therefore, studies on the analysis of fracture in material tensile tests are advanced. In this report, starting point of local necking is thought as starting point of fracture. Three methods are examined to find the starting point of local necking for mild steel sheets. Among these methods, the measurement method using the laser displacement meter is the most accurate.

1. Introduction

In order to reduce the development costs and shorten the development period of dies for plastic working, FEM analysis is widely performed. Numerical simulation using FEM can be applied for investigating forming processes such as forging, cutting, sheet metal forming, etc. To reduce the forming time and costs of parts which have large thickness and complex shape, plate forging instead of cutting, sintering and die casting can be applied. In many cases, the surface quality of the shearing portions is very important when their surfaces slide along those of other parts. In these cases, shear surface is required. It takes a long time to develop the forming process for shear surface due to the trial and error needed, but this development time can be reduced by applying accurate numerical forming simulation with FEM for evaluating shear surfaces [1]. In order to verify the accuracy of the analysis of the basic form of rupture, the FEM analysis of tensile tests including fracture using mild steel and aluminum alloy was investigated. Fracture prediction was performed using Cockcroft-Latham's equation [2] as the ductile fracture criterion, and the fracture shape in the simulation was compared with experimental results [3] [4]. Since the simulation accuracy of the breakage shape by FEM depends on the starting point of local
necking, the accurate prediction of the starting point of necking leads to high accuracy of fracture prediction. Therefore, high precision measurement of local necking is important. The measurement of the local necking starting point in past research [3] [4] was obtained from the shadows observed on the surface of specimens during tensile tests. However, local necking has already developed by the time the shadow is observed in some cases. In this study, local necking was investigated during the tensile test using three methods, namely "measurement of surface shape by laser displacement meter ", "measurement of difference in strain between different gauge lengths" and "luminance distribution of specimen surface " using a mild steel sheet.

2. Tensile test
Tensile test was conducted on cold rolled sheet (SPCE) specimen. The shape of the specimen was JIS No. 5 and the thickness was 1 mm. The dimensions of the specimen are shown in Fig.1. The tensile speed was 1mm/min. The relationship between load and elongation in the tensile test result is shown in Fig.2. The total elongation was 25.4 mm and the maximum load was 7.30 kN. The fracture shape of the specimen is shown in Fig.3. The specimen necked in the thickness direction and had inclined fracture.
3. Measurement of necking

3.1. Measurement of surface shape by laser displacement meter

Using the laser displacement meter, the surface shape along the central axis of the specimen was measured, and the local necking starting point was determined from the surface shape. The resolution in height direction is 0.001 mm. Fig. 4 shows the surface shape when local necking occurs. The minimum height along the measurement was subtracted from the average height of the surface shape to obtain the depth of necking during the tensile test. The first peak from 0 mm to 12 mm in length is considered to be noise due to stray light. Therefore the evaluation of average of height was computed after 12 mm in length. Fig. 5 shows the relationship between the elongation within the gauge length and the depth. Note that inflection points are present at 18.3 mm and 23.7 mm. Since the depth increases from the inflection points, these are the candidates of the points at which necking started. Fig. 6 shows the surface shape of the maximum load (elongation: 13.8 mm) and between inflection points 1 and 2 (elongation: 21.7 mm), and between inflection point 2 and the break point (elongation: 24.2 mm). In the case of diffuse necking, necking occurred in the thickness direction with a large curvature and a length of 36 mm. But with local necking, necking occurred in the thickness direction with a small curvature and a length of 10 mm. Therefore, the starting point of constriction in the thickness direction when diffuse necking occurred was at the elongation of 18.3 mm, and that of local necking was at the elongation of 23.7 mm.
3.2. Measurement of difference in strain between different gauge lengths
Four-gauge points were affixed to the specimen as shown in Fig.7. Strain and elongation between gauge points were measured by video extensometer. The resolution in longitudinal direction of the specimen was about 0.3mm. Local necking occurred between gauge points (2) and (3). It was found that the strain between (1) and (2) or (3) and (4) does not increase after the observation of local necking between gauge points (2) and (3). Fig.8 shows the relationship between strain within gauge points (3) and (4) and elongation within gauge points (1) and (4) at the length of 50mm. The inflection point is located at the intersection of two approximate lines. The elongation at the intersection is 18.6mm. According to Fig.5, diffuse necking starts around the elongation of 18.6mm. It was not the starting point of local necking, suggesting that this technique cannot be used to find local necking.

![Fig.7 Specimen with four-gauge points.](image1)

![Fig.8 Relationship between strain between gauge points (3) and (4), and elongation with gauge length of 50mm.](image2)

3.3. Luminance distribution of specimen surface
When local necking occurs, a shadow is generated at the necking. The luminance distribution was calculated from the recorded moving image to obtain the local necking. The specimen in which local necking occurred is shown in Fig.9, and the brightness distribution is shown in Fig.10. ImageJ was applied for evaluating brightness distribution. The vertical axis of Fig.10 indicates the grey value of 256 gradations and the horizontal axis shows the evaluation range of 8 mm. Local necking indicates the minimum grey value due to the shadow. The relationship between the minimum grey value and elongation is shown in Fig.11. Fig. 11 shows two intersection points produced by three approximate lines. The left intersection is the starting point of diffuse necking at the elongation of 14.3mm. The right intersection is the starting point of local necking at the elongation of 23.7mm.

![Fig.9 Specimen with local necking](image3)
3.4. Comparison
The starting points of diffusion necking and local necking during tensile test were measured using the three methods. The measurement results of each method are shown in Fig. 12. The results obtained by the "Laser" and "Strain" methods agreed with the results of the measurement of the starting point of diffusion necking. The accuracy of finding the starting point of diffusion necking by "Luminance distribution" is influenced by the light applied onto the specimen surface. This means that "Luminance distribution" is not an appropriate method for find diffusion necking. On the other hand, the results of "Laser" and "Luminance distribution" coincided with those of the measurement of the starting point of local necking. Luminance has lower repeatability than other evaluation. The "Strain" method does not have sufficient accuracy for finding the starting point of local necking. Table 1 shows the evaluation of the accuracy of each measurement method. The measurement results of the laser displacement meter were accurate for both diffusion necking and local necking, finding both starting points of diffusion necking and local necking. There are some other methods, such as digital image correlation and thermograph for evaluating diffusion and local necking. Their performance should be evaluated too.
Fig. 12 Starting points of necking obtained by three methods.

Table 1 Evaluation of measurement accuracy.

|                  | Diffuse necking | Local necking |
|------------------|-----------------|---------------|
| Laser            | ○               | ○             |
| Strain           | ○               | ×             |
| Luminance distibution | △          | ○             |

Measurement accuracy: ○-Accurate, △-Inaccurate, ×-Not applicable

4. Conclusions

(1) Diffuse necking and local necking in the thickness direction during tensile tests were measured using three methods, namely "measurement of surface shape by laser displacement mater", "measurement of difference in strain between different gauge lengths" and "luminance distribution of specimen surface" using mild steel sheet.

(2) The measurement of surface shapes by the laser displacement meter was found to be the best method out of the three measurement methods for finding the starting points of diffuse necking and local necking.

References

[1] Takamura M, *Journal of the JSTP*, 35-620 (2012), 17-20
[2] Cockcroft M G and Latham D J, *Journal of the institute metals*, 96 (1968), 33-39
[3] Shimizu D, Takahashi S, Sunaga H, Takamura M, Mihara S and Oohashi E, *6th Pacific-Asia Conference on Mechanical Engineering*, (2017), USB
[4] Shimizu D, Takahashi S, Sunaga H, Takamura M, Mihara S and Oohashi E, *The Proceeding of the 68th Japanese Joint Conference for the Technology of Plasticity*, (2017), 77-78