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NUMERICAL CALCULATION OF TENSILE TEST USING A DUMBBELL-SHAPED IN THICKNESS DIRECTION SPECIMEN

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Summary. This study is the product of a tensile test of a uniaxial tensile specimen having a thinner test section than parallel section, which is a tensile test piece with a dumbbell shape in the thickness direction, fabricated by means of cutting as a preliminary experiment and an evaluation of the mechanical properties of the tensile specimen. In the tensile test, we compared the tensile properties of the dumbbell-shaped in thickness direction tensile specimen with those of conventional tensile specimens. In addition, we analyzed the states of stress and strain in the tensile specimens during a tensile test by using the finite element method.

1 INTRODUCTION

To help protect the global environment, it is desirable in the construction of transport machinery that plates be used with a high specific strength, such as high-tensile steel plates and aluminum alloys. However, it is difficult to manufacture products from these plates because they crack easily during forming. To address this problem, it is necessary to redesign forming dies, which increases production cost.

Metal plates are deformed biaxially during forming. Therefore, an understanding of the nature of biaxial deformation and stress is essential for the processing design of sheet metal forming. In order to gain such an understanding, we must carry out biaxial tensile tests. A cruciform specimen is often used as a biaxial tensile specimen. However, it is difficult to stretch a standard cruciform tensile-specimen to the actual fracture point in a biaxial stress state due to its shape [1], [2]. This problem can be solved by using a cruciform specimen that has a test section that is thinner than the arm section.

In this study, in order to exam the fundamentals of this type of specimen, we fabricated an uniaxial tensile specimen having a dumbbell shape in the thickness direction, which is called a dumbbell-shaped tensile specimen in this paper, and a tensile test was conducted using this specimen. In addition, the uniaxial tensile deformation of the specimen was evaluated by means of a three-dimensional finite element method (FEM) simulation

2 TENSILE TEST

2.1 Tensile specimens

Figure 1 shows the geometrical shapes and dimensions of the dumbbell-shaped tensile specimen, and two JIS No. 13B tensile specimens with thicknesses of 1.0 mm and 3.2 mm. The abbreviated names of these specimens are shown in Table 1. The dimensions of Specimen A are referenced against the JIS No. 13B tensile specimens. The dimension of radius of the shoulder as shown in Figure 1 (a) was determined based on the same ratio as the volume of the shoulder increase as the JIS No. 13B tensile specimens as shown in Figure 1(b).

The specimens were fabricated from a cold rolled steel plate with a thickness of 3.2 mm, with rolling direction angles of 0 °, 45 ° and 90 °. Specimen A and the JIS No. 13B tensile specimens were fabricated by machining. The surfaces of the former were cut by a ball end mill, while the surfaces of the latter were cut by a face end mill. Figure 2 shows photographs of the fabricated tensile specimens. As shown in Figure 2 (c), Specimen C has a dull finish, while the other specimens have a metallic luster resulting from the cutting process, as shown in Figure 2 (b), (c).

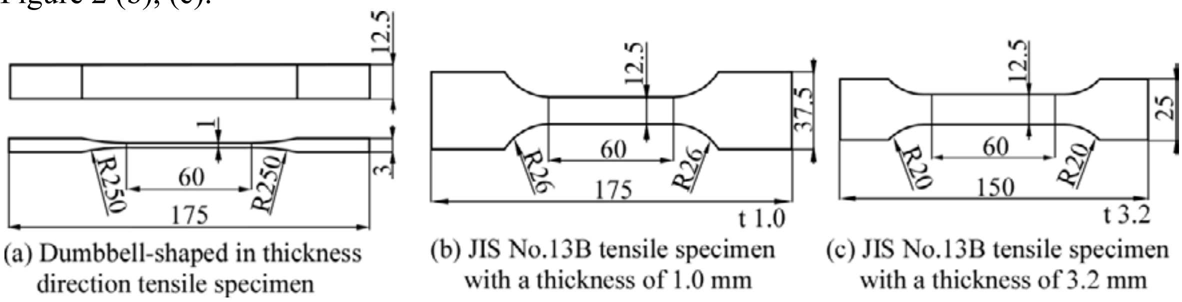

Figure 1: Geometrical shapes and dimensions of tensile specimens

Names of specimen	Abbreviations
Dumbbell-shaped in thickness direction tensile specimen	Specimen A
JIS No.13B tensile specimen with a thickness of 1.0 mm	Specimen B
JIS No.13B tensile specimen with a thickness of 3.2 mm	Specimen C

Table 1: Abbreviated names of specimens

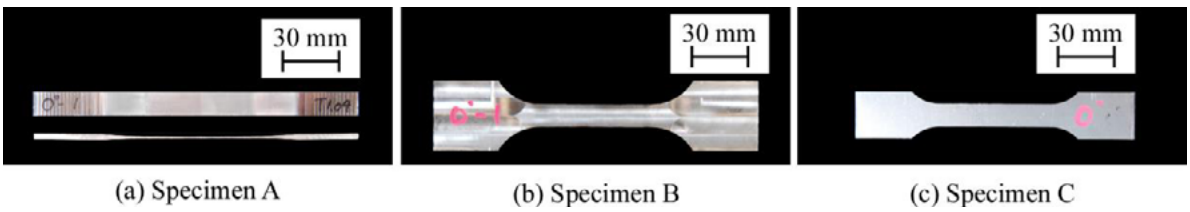

Figure 2: Fabricated tensile specimens

2.2 Uniaxial tensile test

We conducted tensile tests using three types of tensile specimens. The tensile rate and initial distance between chucks were 5 mm/min and 110 mm, respectively, for each specimen.

Figure 3 shows nominal stress-strain diagrams for each specimen. For Specimen A, samples manufactured at 45 ° and 90 ° from the rolling direction yielded similar results, as shown in (a); whereas in the other types, specimens manufactured at 0 ° and 90 ° from the rolling direction yielded similar results, as shown in (b), (c).

Figure 4 shows the relationships between the angle from the rolling direction and the four mechanical properties of tensile strength: total elongation, r-value, and n-value. Each mechanical property was accorded qualitatively. However, quantitative differences in the mechanical properties exist in Figure 4. It is considered that these differences were caused by the differences in the machining processes used in the fabrication of the specimens. The composition of the parallel parts of Specimen C differ from the other specimens; apparently because its surface was affected to a greater extent by rolling. Accordingly, the results for Specimen C showed quantitative differences from the other specimens. Because Specimen B was machined using a face end mill, it was manufactured by simple cutting and thus there is some work hardening.

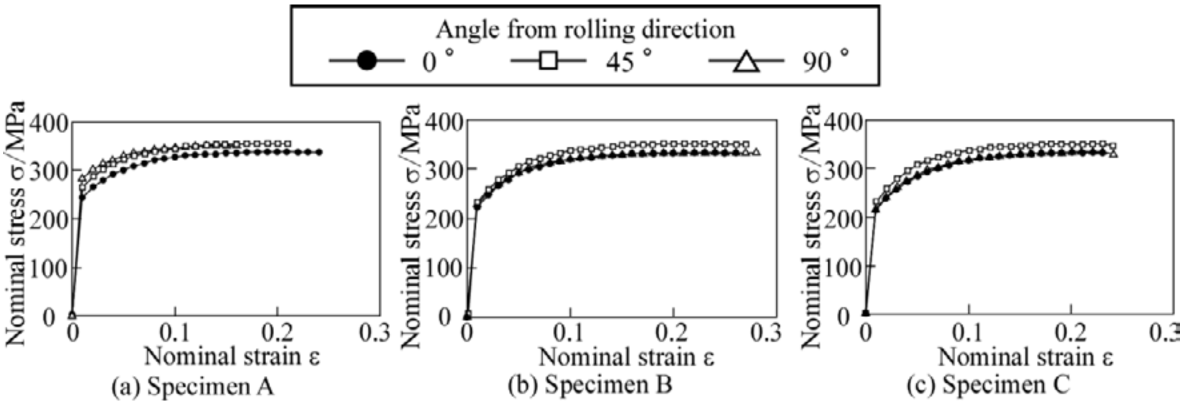

Figure 3: Nominal stress-strain diagrams of three types of tensile specimens

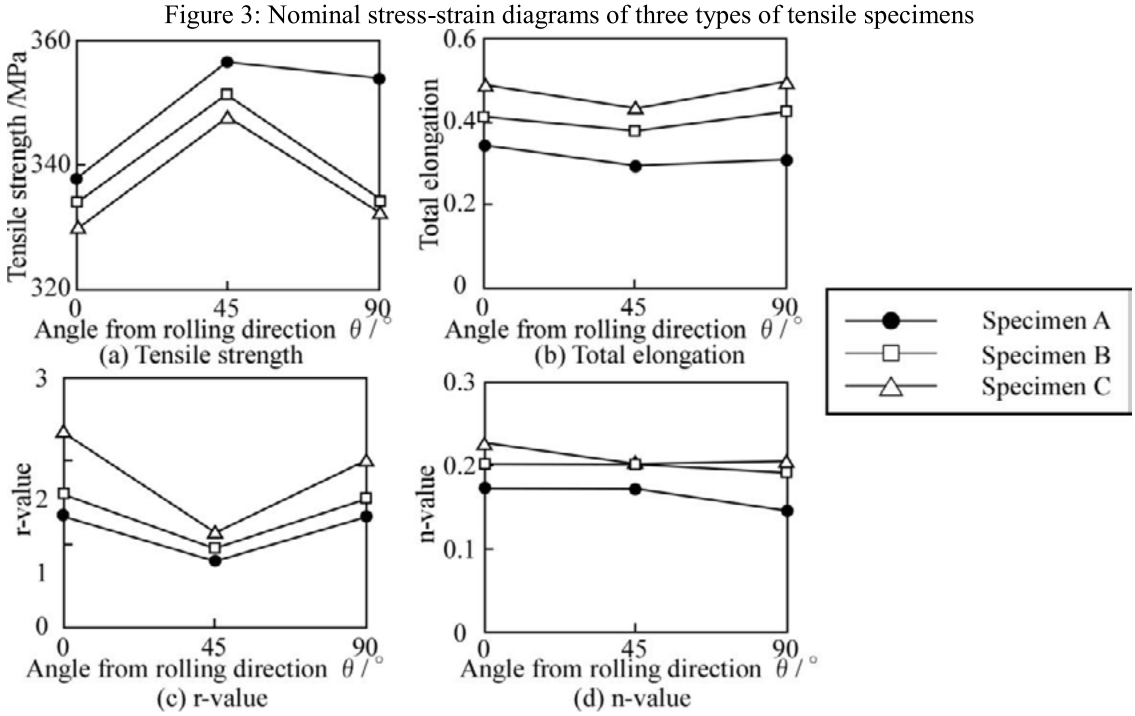

Figure 4: Mechanical properties and angle from rolling direction relationships of three types of tensile specimens

In contrast, Specimen A was machined using a ball end mill, which has a part whose velocity is zero. Therefore, it is considered that it was more powerfully affected by work hardening than Specimen B.

3 ANALYSIS CONDITION

From the results of the tensile test, it was considered that the differences in the machining processes affected the experimental results. Therefore, it is assumed that an ideal condition would not include the influences of the machining process, and we thus investigated the influences only on the specimen configurations. To this end, tensile tests using Specimen A and Specimen B were simulated using FEM. Figure 5 shows the analytical models of the tensile specimens, which simulated the specimens used in the experiment. The models are 1/8th-scale models, as shown in Figure 5. In this analysis, an isotropic property in the elasticity is assumed. The yield stress is 230 MPa, the Young's modulus is 210 GPa, and the Poisson's ratio is 0.3. It is assumed that the material follows the n-th power hardening rule in Figure 6. The Von Mises yield function is used as the yield function. Displacement was applied to the chucking parts of the specimens.

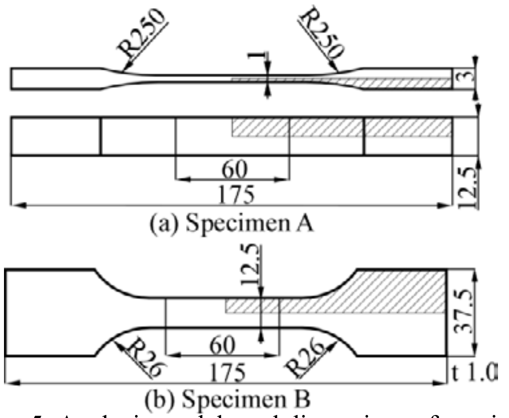

Figure 5: Analysis models and dimensions of specimens

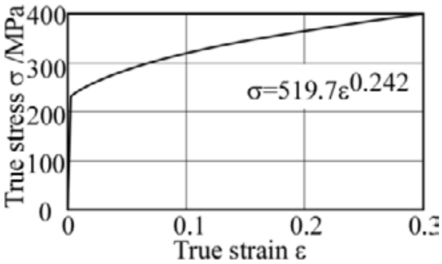

Figure 6: Ture stress-strain diagram simulation used

4 RESULT OF ANALYSIS

Figure 7 shows the patterns of the axial strain distributions of Specimens A and B in the plane of symmetry of the thickness direction in the elastic stage when the axial strain of the parallel part is around 0.07 %. The axial strain is distributed uniformly at the parallel part of Specimen B in Figure 7 (b), and the axial strain peaks near the shoulder. The axial strain is distributed uniformly at the parallel part of Specimen A, as shown in Figure 7 (a), but it does not have a positive peak near the shoulder like Specimen B.

Figure 8 shows the patterns of axial strain distributions for Specimens A and B in the plane of symmetry of the thickness direction near the yield point when the axial strain of the parallel part is around 0.15 %. The axial strain is distributed nonuniformly at the parallel part of Specimen B in Figure 8 (b), and also at the parallel part of Specimen A, as shown in Figure 8 (a). However, it does not have a positive peak (i.e., from one end to the other in the width direction) in the parallel part like Specimen B. For these reasons, it is considered that the axial strain distribution of Specimen A is more uniform than that of Specimen B near the yield point.

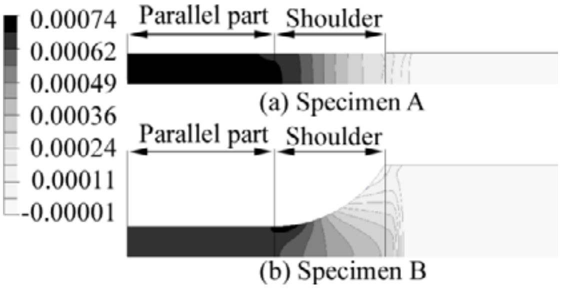

Figure 7: Patterns of axial strain distribution in elastic stage

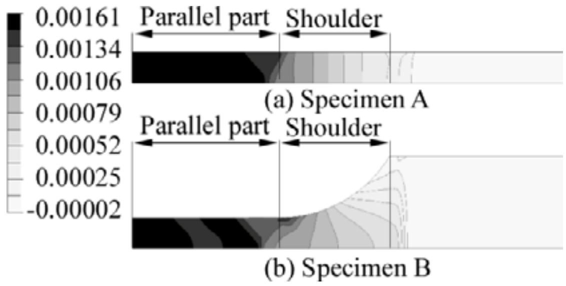

Figure 8: Patterns of axial strain distribution near yield point

Figure 9 and Figure 10 show the patterns of axial strain and axial stress distributions for Specimens A and B in the plane of symmetry of the thickness direction in the plastic stage when the axial strain of the parallel part is around 3 %. Both specimens had uniform distribution of axial strain and axial stress in their parallel parts. Equal strain is distributed in the radial direction in Specimen B, whereas equal strain is distributed in the width direction in Specimen A.

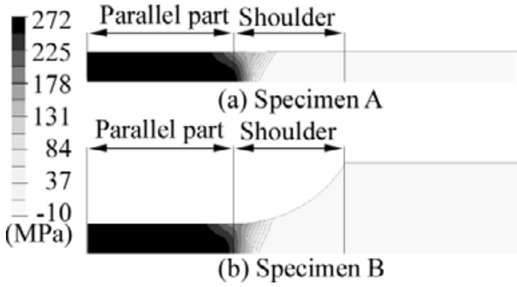

Figure 9: Axial strain patterns distribution in plastic stage

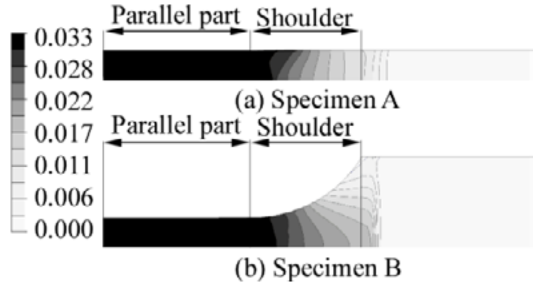

Figure 10: Axial stress patterns distribution in plastic stage

The parallel parts were scaled up in order to better allow an understanding of the states of the parallel parts, and Figure 11 and Figure 12 show these patterns of axial strain and axial stress distribution. Around the center of the longer direction in the parallel part, both specimens had uniform distribution of axial strain and axial stress. Therefore, it is considered possible to use Specimen A as an uniaxial tensile specimen. Around the shoulder, the axial strain at the center of the width was higher than that at the edge of the width for both specimens shown in Figure 11.

The position of the axial strain peak of the dumbbell-shaped tensile specimen in the thickness direction was farther from the center of the longer direction than the other. In addition, the position of the axial stress peak showed the same tendency as in Figure 12. Specimen B had a slip band that is a high-strain zone and about 45 ° from tensile direction, as shown in Figure11 (b); however, Specimen A did not exhibit this tendency in Figure 11 (a).

The axial strain distribution in the parallel part was investigated in order to gain an understanding of quantitatively. Figure 13 shows the transitions of axial strain distribution in both specimens. Line A is the center of the parallel part in the width direction. Line C is the edge of the parallel part in the width direction. Line B is the middle of lines A and C. The axial strain in the center of the longer direction in all three lines is the same value for each of the specimens. However, the values differ at a point 15 mm from the center in Specimen B, as shown in Figure 13 (b), and at 17 mm in Specimen A, as shown in Figure 13 (a). All lines exhibited a peak axial strain near the shoulder. The axial strain suddenly decreased at a position farther from the center than this peak. The peak position of line A, B and C was about 26 mm, 24 mm and 20 mm, respectively, in Specimen B, and about 28 mm, 26 mm and 22 mm, respectively, in Specimen A.

For these reasons, it is considered that Specimen A had a slip band that was not seen to exist in Figure 11 (a). In addition, the distributions of axial strain in the parallel parts of the two types of specimens were different from each other near the yield point. However, their distributions changed and are in accordance with each other in the plastic stage.

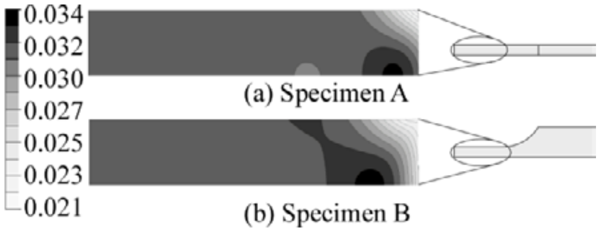

Figure 11: Axial strain distribution patterns in parallel part

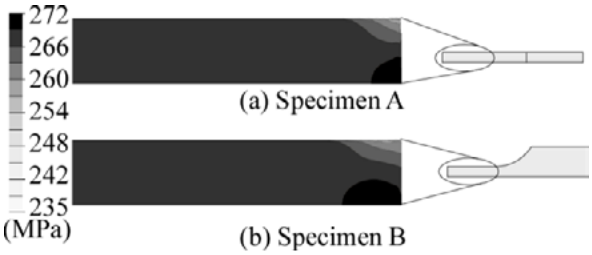

Figure 12: Axial stress distribution patterns in parallel part

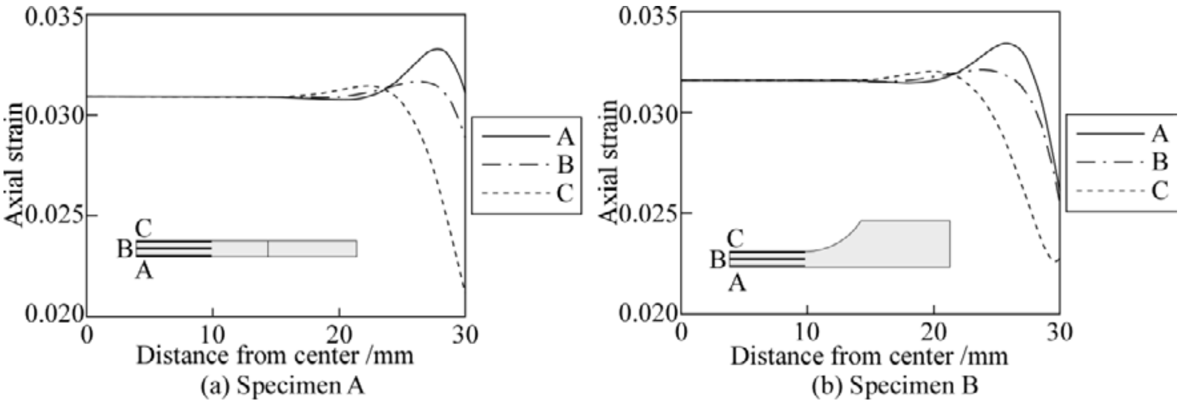

Figure 13: Transitions in axial strain distribution in Specimens A and B

5 CONCLUSION

- We fabricated a dumbbell-shaped tensile specimen in the thickness direction by machining steel plate. The mechanical properties of the specimen were compared to those of conventional tensile specimens by means of a tensile test. A comparison showed that the mechanical properties of the dumbbell-shaped tensile specimen was different from that of convention tensile specimens. This result was considered to be the result of differences in the machining processes.
- Tensile tests of the dumbbell-shaped tensile specimen and a conventional tensile specimen were simulated using three-dimensional FEM analysis. The simulation showed that the two types of specimens had a similar distribution of axial strain and axial stress. Therefore, it is considered that a dumbbell-shaped tensile specimen can be used as a tensile specimen.

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