FUNDAMENTAL FEM ANALYSIS ON TENSILE DEFORMATION OF THE SHEET METAL EMBOSSED ON BOTH SIDES OF THE PLANE

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Summary. In this study, the tensile test of the embossed sheet was conducted and the tensile deformation behavior is experimentally investigated. Also, in this study, the finite-element method (FEM) analysis on tensile deformation of sheet metals embossed on both side of the plane was also carried out. Fundamental tensile deformation behavior of the embossed sheet was investigated and the relationships between deformation mechanism and apparent mechanical properties are considered.

1 INTRODUCTION

Recently, the weight saving of the transportation equipment is recommended from a viewpoint of the low-carbon societies and global environment conservation. Especially, when the weight saving of sheet metals is focused, the aluminum alloy and magnesium alloy that have the high specific strength are adopted and, the sheet metal thinning is conducted. But, the problem that the hardness decrease is appeared by the sheet metal thinning. In order to solve this problem, there is a measure that the sheet metal is applied the periodic embossing. The hardness of the sheet metal increase by embossing. [1]-[4] Sheet metal, in general, has anisotropy that depends primarily on the rolling texture or the recrystallization texture. [5] Also, as for the embossed sheet, in addition to the original anisotropy of the sheet metal, the anisotropy based on the embossing is existed.[6] Also, the work hardening is applied by the embossing. Therefore, in order to use the embossed sheet, the deformation behavior of the embossed sheet need to be investigated in addition to the behavior of the flat sheet.

The flexure behavior mechanism of this embossed sheet has been investigated by the numerical analysis ever. As for the tensile, it is experimentally found that the mechanical properties is changed by the new in-plane anisotropy of the embossed sheet. However, the tensile deformation behavior mechanism that is cause of change in this mechanical property has not been reported.

In this study, in order to comprehend influence to give the apparent mechanical properties by embossing, sheet metals embossed on both side of the plane are applied the annealing treatment and, the tension test is conducted. From this experimnt, change in the mechanical properties is investigated.

Also, the tensile deformation behavior of the embossed sheet is analyzed with finite-element method (FEM) analysis. The fundamental tensile deformation behavior was investigated from the equivalent strain distribution. Moreover, the apparent mechanical properties are calculated by the nominal stress-strain of the embossed sheet and, an influence to give the apparent mechanical properties by embossing is investigated.

2 EXPERIMENTS

2.1 Experimental procedure

Tensile test is conducted with embossed tensile specimens with material of the soft aluminum processed the annealing treatment and a thickness of 1.0 mm. Embossment is conducted by stretch forming with tools as shown in Figure 1. Also, a diameter of tip of the punch is 2.0 mm. Figure 2 shows arrangement of emboss. The concave position is lined up at regular intervals and, the convex position is put the center of four concave positions. Interval between the concave position and the convex position is 3 mm.

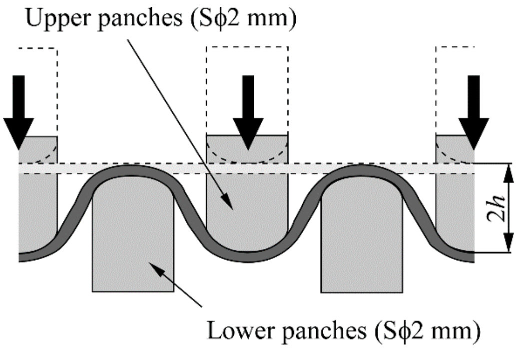


Figure 1: Embossing procedure

Table 1: Embossing condition

Specimen	JIS No.13A
Rolling direction α /°	0
Emboss direction β /°	0, 45
Boss height/mm	1.0
Lubrication	Vaseline

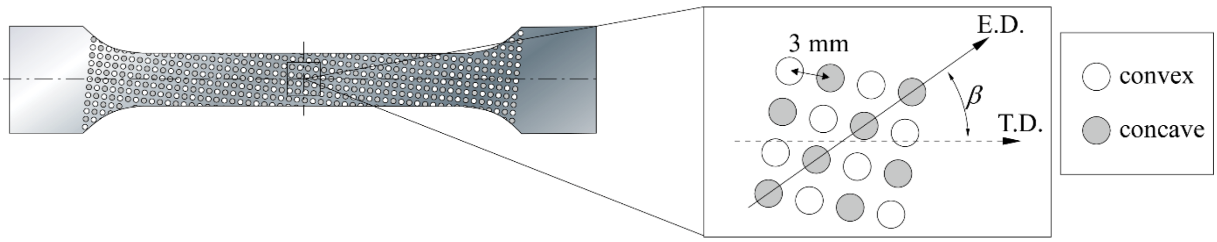


Figure 2: Embossed direction

embossed arrangement, the emboss direction is defined as direction that same emboss is lined up. Tensile specimen is JIS No. 13A and, the sheet rolling direction is made parallel to tensile direction. It was reported that the mechanical properties were changed and anisotropy appeared depending on the boss arrangement. [6] Therefore, the embossed specimen is made by changing embossed direction β of 0 ° and 45 °. Table 1 shows the embossment condition. In this study, an annealing treatment of embossed sheet is conducted. As for an annealing treatment condition, the annealing treatment temperature was 350 ℃ and the soaking time was 2 hour. As for the tensile test, autograph (SHIMADZU-made AG-50kN) is used in this experiment. Experimental velocity is 1 mm/min during the elastic region, and 5 mm/min during the plastic region. Moreover, as for the measure of the elongation, photos during the experiment is used. Pictures are taken at interval of 0.2 mm during the elastic region and 2.0 mm during the plastic region.

2.3 Experimental result

In this study, the tension test is conducted with the embossed sheet performed the annealing treatment. Figure 3 shows the nominal stress-nominal strain diagram and the true stress-logarithm strain diagram. From these diagrams, nominal stress of the embossed sheet is smaller than that of the flat sheet. Moreover, the difference between β= 0 degree and β= 45 degree only shows a little. But, both of nominal stress and true stress at β= 45 degree were higher than that at β= 0. Table 2 shows the mechanical properties calculated in this study. By the nominal stress-nominal strain diagram, the tensile stress is calculated. Also, F-value and N-value are calculated by the true stress-logarithm strain. The tendency that N-value decreased by embossing was confirmed. F-value also decreased by embossing. But, the variation of F-value is much smaller than that of N-value. Therefore, tensile strength of the embossed sheet was smaller than that of the flat sheet because N-value decreased and F-value was almost fixed. As for the r-value, the tendency that this value decreased by embossing was confirmed.

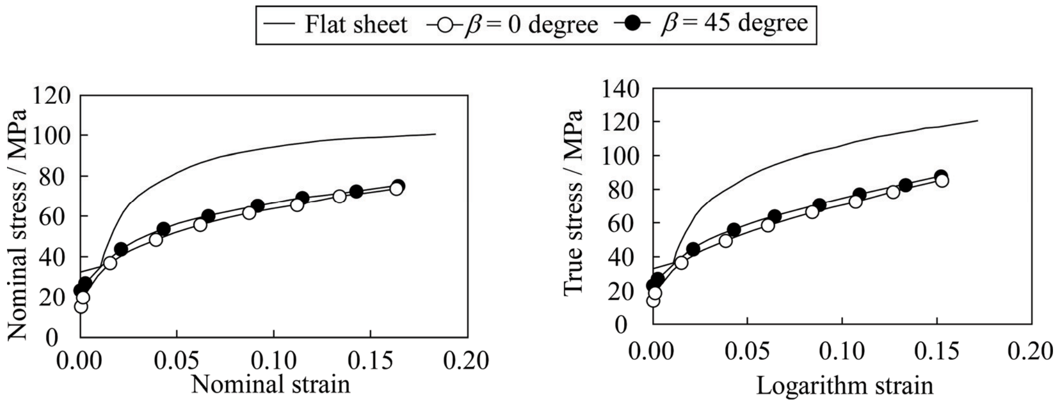


Figure 3: Stress-strain diagram in experiments

Table 2: Mechanical properties in experiments

	N-value	F-value / MPa	r-value	Tensile strength / MPa
Flat sheet	0.249	181.970	0.618	100.095
β = 0 degree	0.411	181.552	0.551	78.659
β =45 degree	0.359	170.608	0.238	83.683

3 ANALYSIS

3.1 Analysis condition

In this study, the fundamental tensile deformation behavior of sheet metals embossed on both side of the plane is investigated from the equivalent strain map and equivalent strain increment map by the finite-element method (FEM) analysis. Moreover, from the apparent mechanical properties, the relationships between deformation behavior and the apparent mechanical properties.

Figure 4 shows the analysis model and dimensions of the specimen. JIS No. 13A is used as the specimen and, the analysis was conducted with the quarter three dimension model so as figure○. In this analysis, specimen is stretch to 25 % forced displacement. Table 2 shows the analysis condition. Assuming material is A1100-O and the isotropic material of von Mises, the analysis about the typical direction of emboss is conducted. The embossed working condition of analysis model is same that of experiment. Moreover, the work hardening by embossing is not considered.

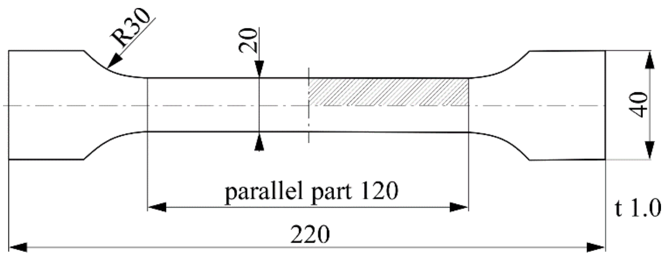


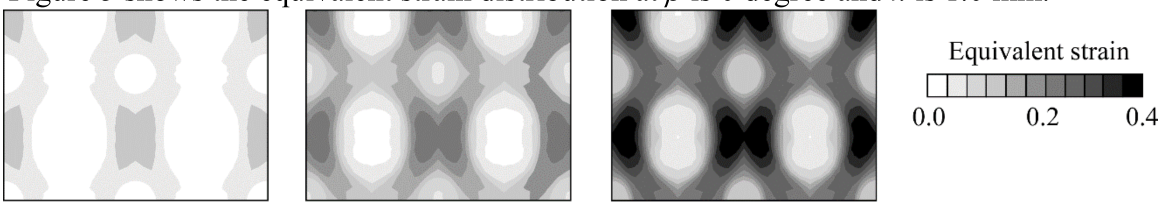
Figure 4: Analysis model and dimensions of a specimen

Table 2: Analysis condition

Yield function	von Mises
Young's modulus / GPa	70
Poisson's ratio	0.33
Yield stress /MPa	35
F-value /MPa	189
N-Value	0.26

3.2 Analysis result

Figure 5 shows the equivalent strain distribution at β is 0 degree and h is 1.0 mm.

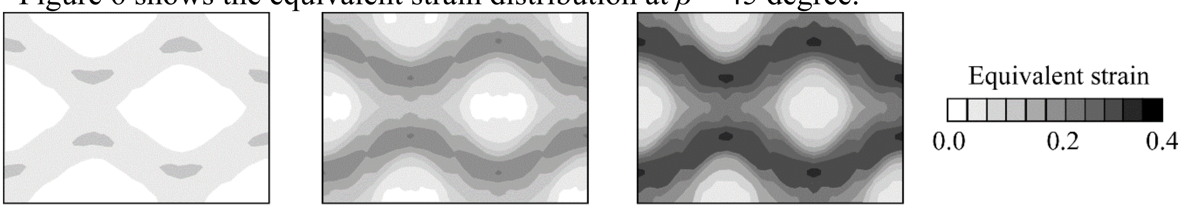


(a) ε = 5 % (b) ε = 15 % (c) ε = 25 %

Figure 5: Change in equivalent strain (β = 0 degree)

When ε become 5 %, the deformation region exist only between bosses. From this figure, the tendency that some networks of deformation were formed and, the deformation was made progress. But, as the tensile was made progress, the tendency that the deformation region increased is confirmed. Moreover, it is confirmed that the front deformation was different from the back deformation. The front deformation region is less than the back deformation region.

Figure 6 shows the equivalent strain distribution at β = 45 degree.



(a) ε = 5 % (b) ε = 15 % (c) ε = 25 %

Figure 6: Change in equivalent strain (β = 45 degree)

The deformation region increase as the tensile is made progress and, the difference between the front and back deformation of the boss part is made as with when β = 0 degree. The mechanism that this difference is made is considered. Figure 7 shows the both deformation of the front and back at the boss part. When the tensile make progress, the bending by rotate shown on figure 7 is carried out. Then, the front deformation at the boss part become shrinkage with a little elongation and, the back deformation become stretch with a little elongation. So, the back deformation region at the boss part is more than that of front deformation region.

Figure 8 shows the nominal stress-nominal strain diagram and true stress-logarithmic

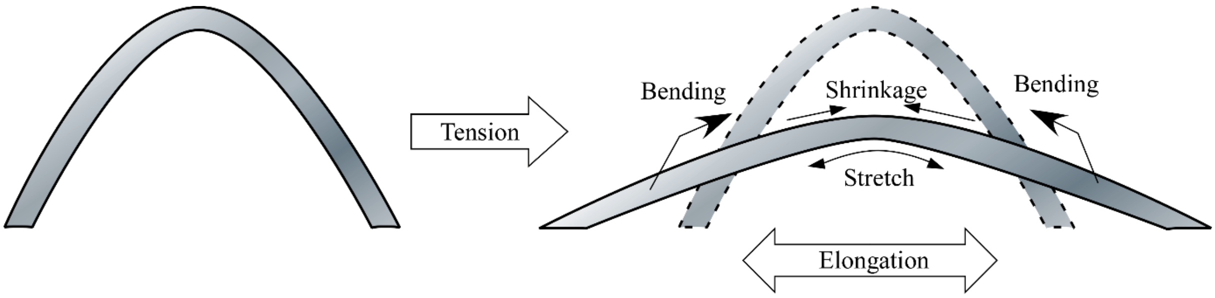


Figure 7: Deformation of the front and back at the boss part during the tensile test

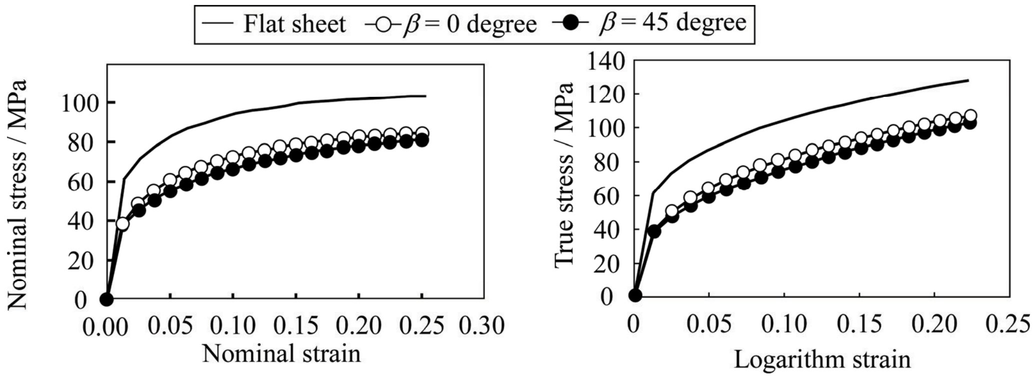


Figure 8: Stress-strain diagrams in FEM analysis

strain diagram of flat sheet and embossed sheet at β = 0, 45 degree. From nominal stress-nominal strain diagram, it is confirmed that both of the tensile load and apparent yield stress decreased. Because actual tensile deformation regions of the embossed sheet are less than that of the sheet metals, tensile load necessary for deformation of the sheet metal decrease, and so the apparent yield stress would decrease. Moreover, the experimental result is reported that because embossed sheets finally become the same flat sheets, these stress-strain diagrams asymptotically approach each other. [7] But, in this analysis, these diagrams didn't asymptotically approach each other. It is considered that this phenomenon was occurred because the work hardening by embossing is not taken into account this analysis result.

Table 3 shows the apparent mechanical properties calculated by true stress-logarithmic strain diagram. The tendency that the apparent N-value (work hardening exponent) increased

Table 3: Apparent mechanical properties by analysis

	N-value	F-value / MPa	r-value	Tensile strength / MPa
Flat sheet	0.259	188.52	0.834	102.602
β = 0 degree	0.338	177.68	0.326	87.859
β =45 degree	0.356	169.35	0.445	82.114

by embossing is confirmed. From figure 8, as the deformation was made progress, the tensile deformation region increased. The apparent deformation resistance decreased because the embossed sheet approach the flat sheet by tension. But, it is considered that the apparent deformation resistance increment increased as the tensile deformation region increased. Because the deformation resistance increment increased, the apparent *N*-value would also increase. Therefore, it is considered that the uniform elongation would become larger by embossing a sheet metal. Also, it is confirmed that the apparent *F*-value (strength coefficient) only shows a little reduction. But, there is little change in *F*-value in comparison with the change in *N*-value. Therefore, the apparent tensile strength decreased because of the equation 1.

$$\sigma = \mathrm{F}\left(\frac{n}{e}\right)^{n} \tag{1}$$

The apparent tensile strength shown on table 3 was calculated by equation 1. Moreover, the tendency that the apparent *r*-value decreased by embossing. The apparent *r*-value at $\beta = 0$, 45 degree is less than that of the flat sheet. When the apparent mechanical of the analysis is compared with that of experiment, same tendency between analysis and experiment is confirmed.

When the analysis result is compared with the experimental result, the tendency of the analysis is almost same that of the experiment. But, because of the work hardening by embossing, the deviation is occurred.

4 CONCLUSION

- We conducted the tensile test with the embossed sheet. As for the embossed sheet, embossed sheets that have the embossed direction $\beta = 0$, 45 degree are used. From stress-strain diagrams from this tensile test, the mechanical properties are calculated. N-value increased by embossing. Also, F-value, r-value, and tensile strength decreased by embossing.
- We analyzed the tensile test of the embossed sheet with FEM analysis. When the equivalent strain is found, there is different deformation between the front and back of the boss part. This difference is occurred because the bending is occurred at the boss part by the rotation. It is considered that the difference of the amount of the deformation is occurred between the front and back because of the bending.
- The mechanical properties of the embossed sheet was analyzed. The apparent N-value increase and F-value, r-value, and tensile stress decrease as with the experiment. It is considered that because the deformation region increase as the tensile deformation make progress, N-value increase. Moreover, as n-value increase, tensile strength decrease because of the equation 1. The same tendency of stress-strain diagrams between the analysis and experiment was confirmed. But, the deviation of these properties is occurred because the work hardening by embossing is performed.

APOLOGY

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