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FEM ANALYSIS ON THE DEFORMATION BEHAVIOR OF FLANGE PORTION DURING EARLY STAGE IN DEEP DRAWING OF DUPLEX EMBOSSED SHEET METAL

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Abstract. Duplex embossed sheet metals are very useful due to their high rigidity. Furthermore, it is very interesting that the periodic configurations given by embossing brings a new macroscopic feature into a sheet metal. In this study, in order to confirm the effect of only sub-macroscopic structure, which was the configuration given to sheet metal by duplex embossing process, the material was set to isotropy, and FEM simulation was carried out to investigate about the deformation behavior of flange portion during the early stage in deep drawing of duplex embossed sheet.

1 INTRODUCTION

In the recent decades, the energy conservation is more and more demanded. And around this opinion, many strategies of lightweight were proposed. One of the representatives is using the thinner sheet metal. However, the rigidity and forming ability of thinner sheet metal become poor when compare with the thick sheet metal. To overcome this problem, embossing process was proposed due to their high rigidity.

As the sheet metal subjected to duplex embossing process which the sheet metal subjected to embossing process on both sides. The cross section changed to be wave, and the sheet metal will be given a periodic convex-concave structure. It is considered that there will have a new anisotropy depends on this sub-macroscopic structure. Until now, uniaxial tensile properties have been investigated, and peculiar features of duplex embossed sheet have been reported [1]-[3]. One of the features is the low Lankford value (r-value). According to the classical theory, this means that deep drawability could become lower in embossed sheets than that in a plane sheet. However, there is only a few investigations about the deep drawability of embossed sheet metal [4]. And in some cases, contrary experimental results have been reported [5].

Here, in this present study, in order to confirm what happens at flange portion during early stage in deep drawing deformation of duplex embossed sheet, simulation of deep drawing test was conducted by FEM analysis carried out using SIMUFACT 13.0. In this FEM analysis, 1/4 symmetry model was used to reduce the analytical time and expense. And in order to confirm the effect of sub-macro structure on flange deformation behavior, which was the configuration given to sheet metal by duplex embossing process, the material was set to isotropy. The punch force-stroke response in the deep drawing deformation, the average strains in both radial and circumferential directions, the equivalent strain increment distribution map are evaluated numerically at early stage in deep drawing. From these results, the flange deformation behavior was investigated. And also it affirms the results of previous experimental results[6].

2 DUPLEX EMBOSSING PROCESS

Figure 1 shows the schematic of analytical models of duplex embossing process in this study. As shown in this figure, about the duplex embossing process, only upper die is movable in vertical direction. The embossing height *h* is defined as the half of upper die stroke. Moreover, it is considered that the mechanical characteristics of regular sheet metal depend on the aggregate structure caused by rolling process. And as it subjected to duplex embossing process, the apparent mechanical characteristics of duplex embossed sheet metal changed to depend on this convex-concave structure. So, it is necessary to define the relationship between the rolling direction and embossing direction. Firstly, about the embossing direction, the direction which the same orientation (convex or concave) became linear was defined as embossing angle is 0°. The angle between this embossing direction and the rolling direction was defined as γ. Furthermore, the distance between the centers of adjacent convex and concave bosses was defined as 3mm.

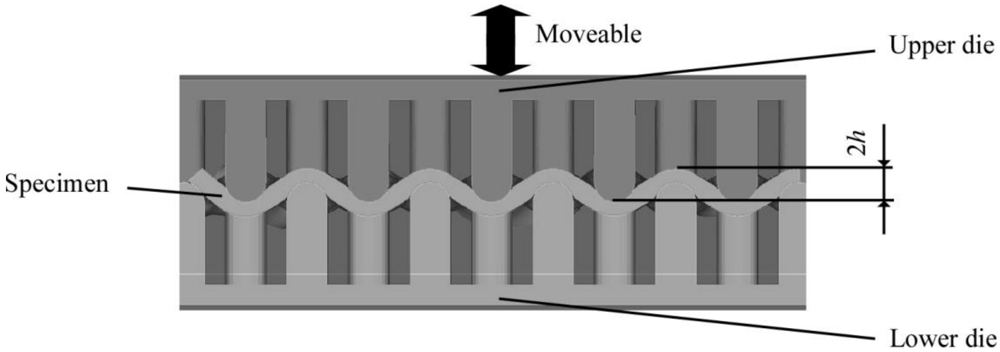


Figure 1 : Duplex embossing process models

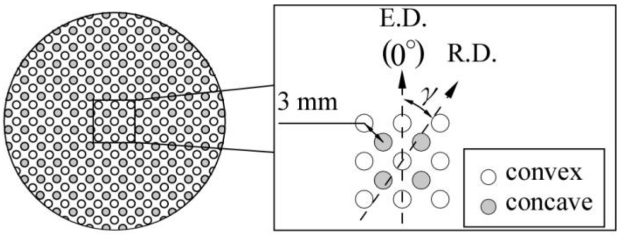


Figure 2 : Definition of the relationship between embossing direction

3 ANALYSIS

3.1 Analytical condition

In fact, the work hardening is existed in the duplex embossed sheet metal caused by this process. So, in order to as far as possible simulate the deep drawing test using duplex embossed sheet accurately. The analysis of duplex embossing process is also essential. Here, in this present study, the analysis of duplex embossing process was conducted firstly. Moreover, in this FEM analysis, 1/4 symmetry model was used to reduce the analytical time and expense. Figure 3 shows about the 1/4 specimen used in this FEM analysis of deep drawing test.

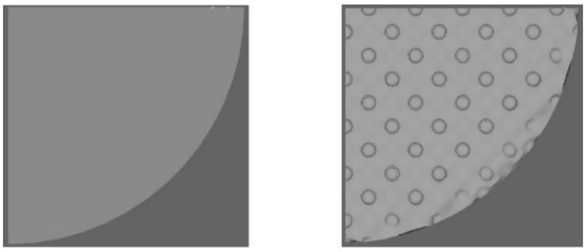

(a) (b)

Figure 3: 1/4 specimen model (a) Plane sheet (b) Duplex embossed sheet

Analytical conditions are listed in Table 1. The diameter of the circular specimen (before duplex embossing process) was set to be 60mm. And the material of specimen was set to be Aluminum alloy. The specific information of this material (Young modulus, n-value, F-value) were also listed in this table. About the γ, in this study, the material was set to isotropy, it can be approximately considered that it is similar to γ=0°. The embossing height *h* was 1mm, and the thickness of the sheet metal before duplex embossing process was 1.0mm. Furthermore, the mesh size of specimen model was set to 0.5.

Table 1: Analytical condition

Specimen	Φ60
Material	Aluminum
γ/°	0
Embossing height *h*/mm	1, 0(plane)
Thickness (before embossing process)/mm	1
Young modulus/ GPa	69
n-value	0.2757
F-value/ MPa	155
Mesh size	0.5

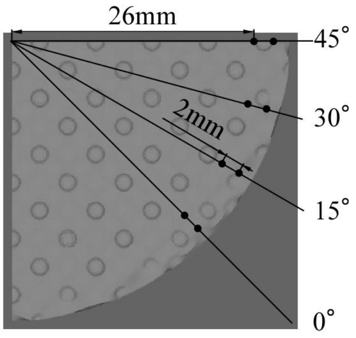


Figure 4 : Measured positions

Next, Figure 4 introduces the flange deformation measurement method in this study. The measured portions in this analysis were set to 26mm and 28mm from the center of specimen respectively. Because the material was set to be isotropy in this present study. It is considered that there only have one kind of anisotropy which depends on the periodic embossing structure. So in the circumferential direction, the measure points were established from embossing direction is 0° to 45° by 15° interval of 1/8 specimen as the symmetric of embossing structure.

About the deep drawing test set-up, here, the flat head punch was used to conduct the test, and diameter and shoulder radius of it was 29 mm and 3mm respectively. Moreover, due to the apparent thickness of plane sheet and duplex embossed sheet metal (distance between convex and concave bosses) is different from each other. Focus on this issue, in this analysis, the die was set the same as the experiment which was conducted previously. In case of plane sheet, the inner diameter of die was 31.5 mm. And in case of duplex embossed sheet, the inner diameter of die was changed to be 33.5 mm. About the conditions of deep drawing test, the blank holder force was set to be 3kN, and the friction coefficient was set to 0, it can be considered to similar with perfect lubricated state.

3.2 Calculation method

In this present study, the strain component in the radial and circumferential direction were calculated in order to evaluated the flange deformation behavior. First, about the radial direction strain, it was calculated from average variations of the length of two measurement points in the same embossing direction. On the other hand, about the circumferential direction strain component, it was calculated from the average circumferential length with radius r_{ave} of the center point of the two measurement points in the same embossing direction. The r_{ave} can be calculated by the following equation.

$$r_{ave} = \frac{r_0 + 2(r_{15} + r_{30} + r_{45} + r_{60} + r_{75}) + r_{90}}{12} \qquad 1)$$

Where the r_α denotes the average radius of the corresponding embossing direction. Because it is considered that the embossed sheet metal is 1/8 symmetry in case of the material is isotropy. So, r_{ave} could be calculated by the following equation simply.

$$r_{ave} = \frac{r_0 + 2r_{15} + 2r_{30} + r_{45}}{6} \qquad 2)$$

After the calculation of r_{ave}, the average circumferential length L could be calculated easily by the following equation.

$$L = 2\pi\, r_{\mathrm{ave}} \qquad 3)$$

In the end, this average length was used to calculate the average circumferential strain.

4 RESULTS

Figure 5 shows the punch force-stroke curves in deep drawing test of plane sheet and duplex embossed sheet. Comparing these two curves, it can be easily found that the punch force of embossed sheet in case of h=1mm is smaller than that of plane sheet no matter how much the punch stroke is. It is considered that the deep drawing deformation resistance of embossed sheet is smaller than that of plane sheet.

Figure 6 shows the variations of center points coordinate of the two measurement points in case of different embossing directions and punch stroke. From these figures, it can be found that at the beginning of the analysis of deep drawing test (stroke=0~4mm), the positions of these center points are almost the same with each others. And from the punch stroke is 6mm, it was confirmed that the moving toward center speed of plane sheet is faster than that of duplex embossed sheet metal. It is considered that in the radial direction, the duplex embossed sheet metal can be deformed more easily than plane sheet because of the existence of rotatable portion. Next, from the punch stroke is 16mm, it can be found that the difference of the center points positions coordinate between plane sheet and duplex embossed sheet started to become smaller as punch stroke is increased. It can be thought that the tendency can be reversed in the end of deep drawing test. In other words, about the cup height, duplex embossed sheet will be smaller than that of plane sheet.

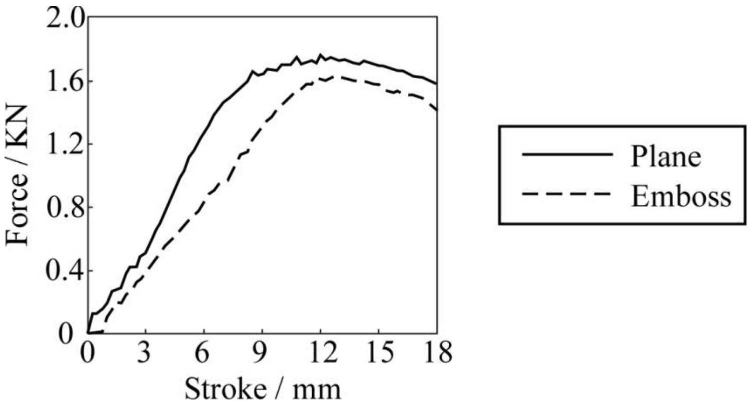


Figure 5: Force-Stroke curves of deep drawing test of plane sheet and duplex embossed sheet

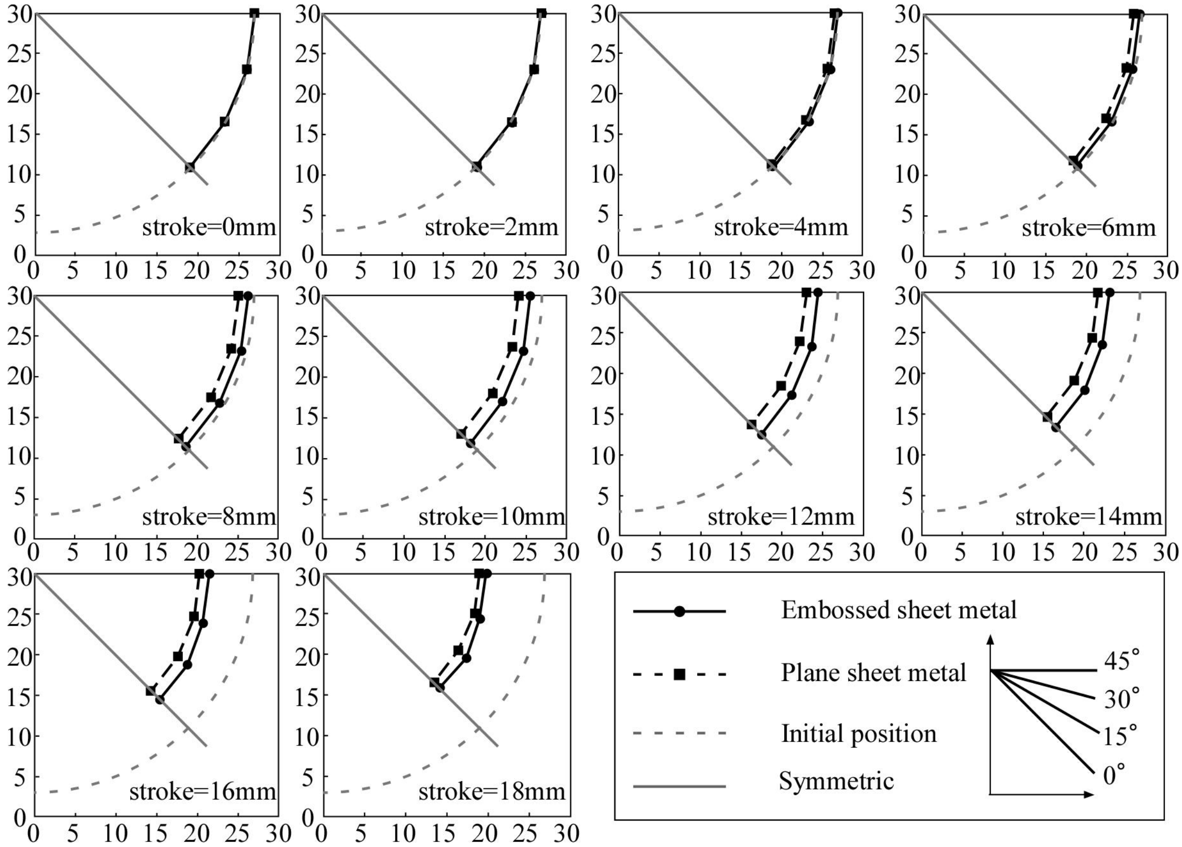


Figure 6: Variations of the center points coordinate of two measurement points in case of different embossing directions and punch stroke

Figure 7 shows the variations of strain distribution of the flange portion deformation in deep drawing. Figure 7 (a) is the relationship between radial direction logarithmic strain and punch stroke. From this result, it can be found that about the radial direction logarithmic strain, plane sheet is the same as duplex embossed sheet metal at the beginning of deep drawing deformation (stroke=0~2mm). Next, as the punch stroke is developed, the radial direction logarithmic strain of them were increased altogether. Moreover, the embossed sheet is smaller than that of plane sheet. And then there have a tendency that this strain of plane sheet will be decreased as the stroke increased and become smaller than that of duplex embossed sheet.

Figure 7 (b) shows the relationship between circumferential and radial direction logarithmic. Here, in this present analysis, it can be found that about the plane sheet, these two kinds of strain changed in the same degree. It is considered that the strain ratio is approximated to be -1. And as the deep drawing test is developed, it final stage of deep drawing, the strain ratio become larger. It it thought that the thickness of flange portion will be increased. On the other hand, about the duplex embossed sheet, it could be found that the slope of the curve is bigger than that of plane sheet. It can be considered that the thickness increase of duplex embossed sheet is larger than that of plane sheet. Therefore, it is also considered to be the reason which lead to the cup heights are different with each other.

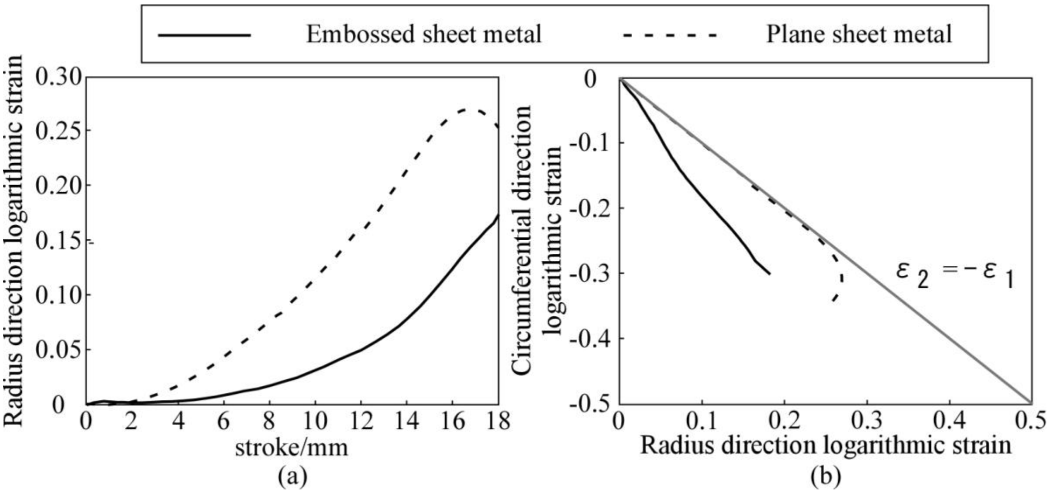
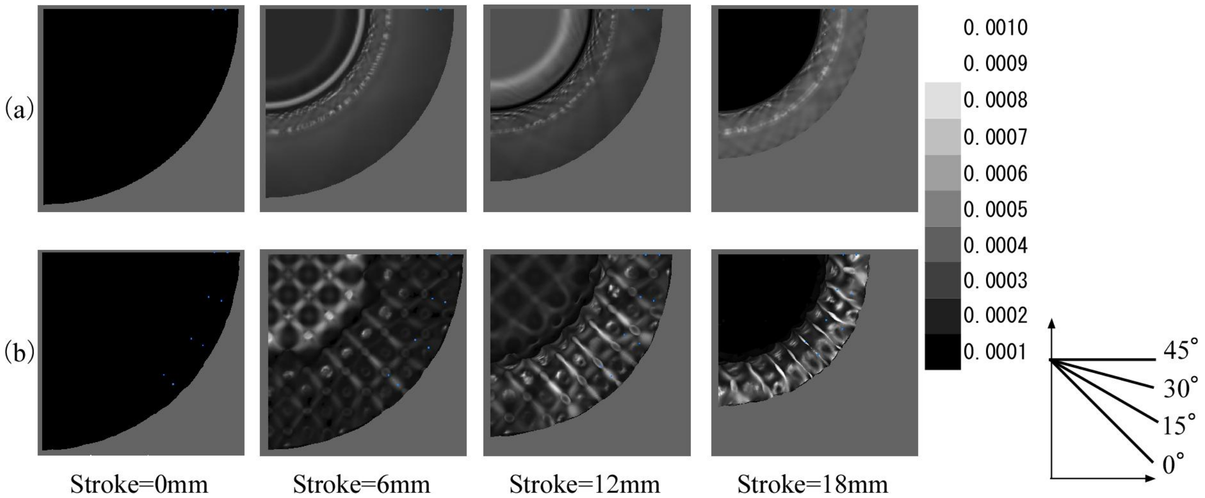


Figure 7: Variations of strain distribution (a) Relationship between radius direction logarithmic strain and punch stroke; (b) Relationship between circumferential and radius direction logarithmic

Finally, Figure 8 shows the equivalent strain increment distribution maps in case of different punch stroke. Figure 8(a) is the sequence of deformation of plane sheet. Paying attention to the flange portion, it can be found that the flange portion of plane sheet deformed uniformly as the punch stroke is increased. And the equivalent strain increment became maximum at the shoulder portion of die. On the other hands, Figure 8(b) is the distribution maps of duplex embossed sheet. It can be confirmed that at the flange portion of duple embossed sheet, the portion near the place where the embossing direction is 0° become the largest. It can be considered that it is derived from the anisotropy depend on embossing distribution. And because of the existence of rotatble part, the variation is not uniform, the portion between bosses is the largest relatively. And at the last half of the deep drawing, the difference depend on embossing direction became not very obvious.



Stroke=0mm Stroke=6mm Stroke=12mm Stroke=18mm

Figure 8: Variations of equivalent strain increment in case of different punch stroke
(a) Plane sheet ; (b) Duplex embossed sheet

5 CONCLUSIONS

In the present study, the flange portion deformation behavior of duplex embossed sheet metal was investigated numerically. The results obtained from this study are summarized as following.

- The deep drawing deformation resistance of embossed sheet (h=1mm) is smaller than that of plane sheet.
- About the moving toward center of the flange portion in deep drawing, when the punch stroke is increased, plane sheet is larger than that of duplex embossed sheet. And in the second half of the deep drawing, the embossed sheet start to be larger than that of plane.
- As punch stroke is developed, the radial direction logarithmic strain of both of plane sheet and duplex embossed sheet increased. Furthermore, duplex embossed sheet is smaller than that of plane sheet. However, in the second half of the deep drawing, the strain of plane sheet started to decrease.
- Strain ratio of duplex embossed sheet is larger than that of plane, it is considered that the apparent thickness increase of flange portion in deep drawing deformation of duplex embossed sheet is larger than that of plane sheet.
- About the equivalent strain increment distribution, duplex embossed sheet is different from that of plane sheet, it was deformed not uniformly, and become the largest as at the embossing direction is 0°.

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