



A study of the domed drawing displacement characteristics of a high-tension steel plate (SGAFC980)

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Received: 20 November 2020 / Accepted: 27 September 2021 / Published online: 3 November 2021
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Abstract

In order to reduce the weight and energy of vehicles, the steel sheets used in automotive manufacturing must be made of materials with a thinner material thickness and higher strength both to reduce the weight and save energy. For this reason, the use of high-tensile steel sheets is increasing. However, the drawing process in these cases is challenging due to the characteristics of high-tensile steel sheets. In order to solve this problem, a dome-shaped drawing die was manufactured and the tensile displacement characteristics of the material were studied using a high-tensile steel plate (SGAFC980). During the drawing process, the experiment involved changing the drawing speed, the pressure of the blank holder, and the size of the blank, which are the key factors. The results showed that when the drawing speed was slow, the inflow of the material was smooth, and the occurrence of cracks could be minimized. Pressure on the blank holder facilitates the inflow of the material and when set appropriately low, it does not cause wrinkles. As the size of the blank decreases, the clamping force applied by the blank holder decreases, and less tensile displacement of the material occurs. After the drawing process, changes in the materials were analyzed with an electron microscope, and the displacement characteristics of each location used in the experiment were considered.

Keywords Blank holding force · Blank size · Drawing processing displacement · Drawing processing speed · Drawing speed · Dome-shape drawing die

1 Introduction

In the automobile manufacturing process, stamping refers to the process of manufacturing a three-dimensional panel at the request of a designer. In the stamping process, the sheets are made into parts through several successive pressing processes. Most of the shapes of automotive panels are determined by the drawing mold, which is the first process, with drawing processing then using a punch to push the material into a die to make a seamless hollow container [1].

The current steel sheets used for the manufacturing of automobiles are developed in a direction to reduce the thickness of the material and lighten the weight in order to reduce the weight of the vehicle and save energy. The high strength of the material is required, and the processing of the sheets includes welding or other joining techniques, but it is necessary to produce parts of the desired shape and strength at once.

Lee et al. conducted a study of the formability of 980 MPa ultra-high-strength steel sheets and a method of generating and reducing springback using a hat-type mold [2]. Guo et al. [3] studied the size effect on the displacement behavior via the dome-shaped micro-deep drawing of steels with different grain sizes and thicknesses. With regard to the cylindrical deep drawing process, many studies have assessed changes in the product thickness according to different process variables [4–7]. When molded with a uniform load, the mold life can be improved and the product quality is also excellent [8]. In addition, experiments and analyses were conducted on the deep drawing formability of square, rectangular,

Technical Editor: Lincoln Cardoso Brandao.

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elliptical, and small parts, and another study concentrated on the thickness change and formability of the product, the effect of the blank holding force, the occurrence of wrinkles on the flange, and warm drawability characteristics [9–17]. In addition, drawings of domed parts were analyzed and numerical simulations were performed. A theoretical basis was provided by identifying important process parameters such as those related to wrinkling and fractures [18]. Thomas et al. drew a hemispherical dome bottom cup using an aluminum drawing steel sheet for automobiles, testing the aluminum 6111 alloy; during the drawing process, the effects of controlling the force of the blank holder were investigated. The distribution of the displacement of the domed cup according to these effects was studied [19].

As a result of analyzing the research trends in this field, it was found that there were many studies on the spring-back of high-tensile steel sheets, whereas studies focusing on the drawing displacement of high-tensile steel sheets were found to be insufficient. The demand for materials with high strength and extreme variations is increasing with weight reductions and fuel efficiency improvements in automobiles. In this study, a dome-type drawing mold was produced and tensile and compressive displacement characteristics with changes in the blank size of a high-tensile steel sheet, different pressures of the blank holder, and changes in the drawing speed were studied.

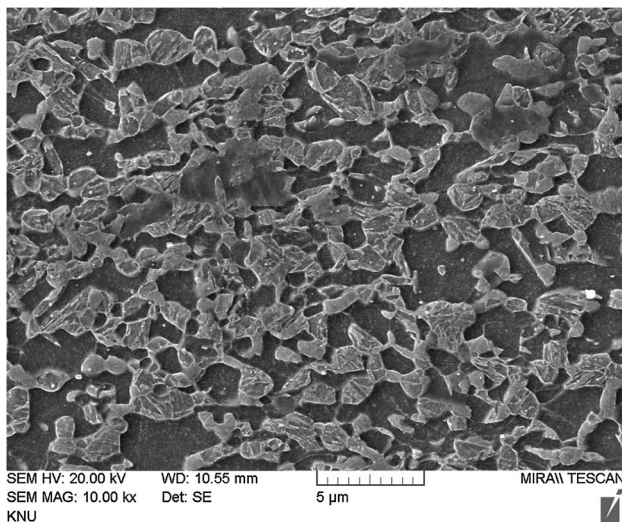


Fig. 1 SEM image of the test material (SEM MAG: 10.00kx)

2 Dome drawing die

2.1 Material analysis and domed drawing product design

The processed plate used in this experiment had a tensile strength of 1 GPa and was the class SGAFc 980 material, which has recently been specified for wider use in the automobile industry. The material thickness of this material was 1.2 mm. This is a developed material for the purpose of reducing the weight and maintaining the strength of automobiles via the use of a high-strength, high-ductility 1 GPa class trip steel.

Figure 1 shows an image of the test piece. The piece mainly consists of two phases, with the white part being a solid martensite and ferrite matrix structure and the black part an austenite structure. In addition, the components of the specimen used in the experiment are listed in Table 1.

The material used in the experiment was considered to contain some impurities [C (0.0729%), Si (0.408%), Mn (2.277%), P (0.0068%), and S (0.007%)] in the matrix structure, meaning that it was 96.305% pure.

For the mechanical test, a tensile test piece for a plate (KS No. 5) was produced in the rolling direction, and a tensile test was performed. These results are shown in Table 2. The maximum tensile strength was 1085.90 MPa, indicating an ultra-high-tensile steel plate that is difficult to deform.

Drawing products should be of low tensile strength and relatively easy to deform, but as a result of analyzing the

Table 1 Component analysis of the specimen

	Contains	Chemical composition (%)	Units	Note
SGAFc 980	C	0.0729	wt.%	
	Si	0.408	wt.%	
	Mn	2.277	wt.%	
	P	0.0068	wt.%	
	S	0.0007	wt.%	
	Fe	96.305	wt.%	
	Total	99.0704	wt.%	

Table 2 Mechanical test results

	Maximum tensile load (N)	Maximum tensile strength (MPa)	Breaking stroke (mm)	Breaking load (N)	Breaking stress (MPa)
SGAFc 980	32,576.9	1085.90	8.08614	22,935.4	764.514

experimental material here, it was found that it was difficult to deform the material via a drawing process. Accordingly, displacement by springback or warping can be expected of this ultra-high-tensile steel sheet.

Figure 2 shows the drawing product applied during the experiment. Considering the difficulty of molding, the punch was made into a dome shape with SR249 applied, and the height of the product was set to 40.5 mm and R18 mm. These values were applied to facilitate the inflow of the material to the inlet of the die.

Here, **A**, **B**, **C** and **D** shown in the product drawing, indicate the measurement positions upon a product change after drawing processing.

2.2 Dome drawing die production

As shown in Fig. 3, the thickness of the die plate was set to be 25 mm lower than the height of the product; this thickness of the die plate secured a product height of 40.5 mm after applying a base plate of 20 mm. Considering the occurrence of springback, the shape of the punch was SR249 mm, and a mold of 600 × 600 × 480 mm (width × length × height) was manufactured.

To conduct the experiment in a general-purpose press, the die plate was installed on the upper die of the die and the blanking punch was installed on the lower part. To run the test while changing the pressure of the blank holder, blank holder force of 176.5 N was set by applying 12 gas springs, each with the pressure of 14.71 N and a stroke of 50 mm to the mold.

3 Drawing experiment and analysis

3.1 Experimental order and conditions

The experimental material is shown in Fig. 4. Using a screening process printing method, dots having a diameter of 2 mm were applied to the entire surface of the test piece

at intervals of 5 mm. After the experiment, the amount of displacement was measured. The press machine used in the experiment was a 350-ton double-crank press.

In the first experiment, different blank sizes were used, i.e., Ø380 mm, Ø350 mm, Ø320 mm, and Ø290 mm, and the drawing speed was set to 10 m/min. During this experiment, blank holding pressure of 176.5 N was applied, and the tests were conducted with a sufficient amount of lubricant on the surface of the product.

In the second experiment, the size changes of the blank, the pressure of the blank holder, and lubrication conditions were identical to those in the first experiment, and the drawing speed was changed to 15 m/min.

In the third experiment, the sizes of the blanks used were Ø350 mm, Ø320 mm and Ø290 mm, and the drawing speed was set to 10 m/min. This time as well, blank holding pressure of 176.5 N was applied, and the test was conducted with sufficient lubrication on the surface of the product, as in the previous conditions. In addition, four gas springs were removed to facilitate material inflow, and pressure of 117.7 N was applied to the blank holder.

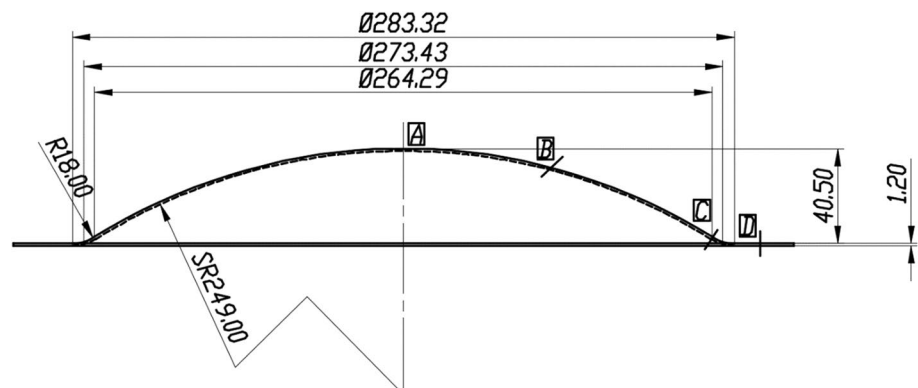
In the fourth experiment, the size changes of the blank and the pressure of the blank holder were identical to those applied in the third experiment, and the drawing speed was changed to 15 m/min. The lubrication conditions were identical as well.

As shown in Table 3, die parts are represented as 1-3810, 1-3510, 1-3210, 1-2910, etc. The first digit indicates the order of the experiment, the next two digits represent the size of the blank, and the last two digits are the drawing speed.

3.2 Drawing simulation

In this study, the shape of the product is a cylindrical dome, and the amount of displacement according to the location of the entire product was analyzed using Auto Form-Forming Solver R8. These results are shown in Fig. 5.

Fig. 2 Dome-shaped drawing product (thickness: 1.2 mm)



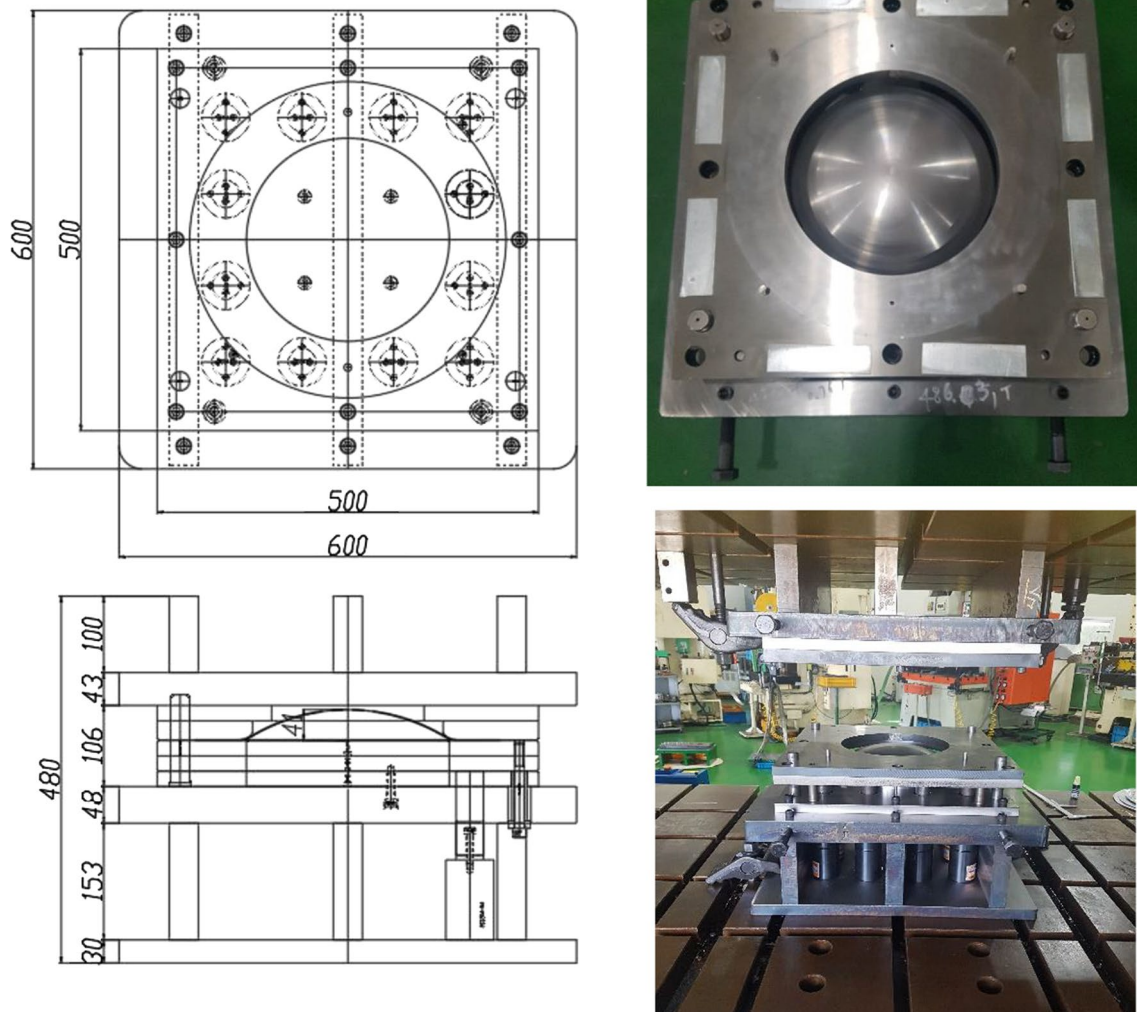


Fig. 3 Dome-shaped drawing die-set (design drawings and manufactured molds)

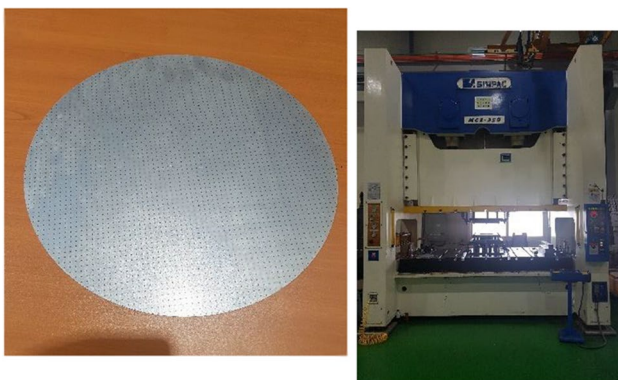


Fig. 4 Materials and press used in the experiment

The process parameters used in the analysis are shown in Table 4. As the material used in the experiment was judged such that the amount of change for tension and compression would not be large, the analysis model was set in the same direction without considering anisotropy, and the analysis was conducted.

The material was made to flow smoothly considering the boundary conditions. With the drawing punch speed in the Z-axis direction set to 10 m/min and 15 m/min, the step increment was 1.0 mm, and when the height of the product was increased to 40.5 mm, the variation of the product was investigated.

In the 1-3810 case, it showed a maximum thickness strain of 0.058% at position A and tended to decrease by 0.036% at position B and by 0.056% at position C, and the thickness strain increased by 0.022% at location D. According to the

Table 3 Die parts for the experimental classification

Test order	Test material	Blank Size (mm)	Drawing Speed (m/min)	Blank holder Pressure (n)	Die part
1	SGAFC 980 thickness 1.2 mm	380	10	176.5	1-3810
		350			1-3510
		320			1-3210
		290			1-2910
2		380	15		2-3815
		350			2-3515
		320			2-3215
		290			2-2915
3		380	10	117.7	3-3810
		350			3-3510
		320			3-3210
		290			3-2910
4		380	15		4-3815
		350			4-3515
		320			4-3215
		290			4-2915

size of the blank, the amount of strain decreased slightly, and it was found that no cracking occurred.

Even according to a secondary analysis, no cracks occurred anywhere on the surface of the product. In the 2-3815 case, the thickness strain at position **A** showed a maximum of 0.057%, tending to decrease by 0.034% at position **B** and by 0.057% at position **C**. The thickness strain increased by 0.024% at location **D**. As a result of a comparison with the first analysis, it was noted that the strain rate decreased slightly at positions **A** and **B** as the drawing speed was increased, but it increased at positions **C** and **D**.

According to the results of the third analysis, no cracks occurred anywhere on the surface of the product. In the 3-3810 case, the thickness strain at position **A** showed a maximum of 0.054%, tending to decrease by 0.034% at position **B** and by 0.06% at position **C**. The thickness strain increased by 0.023% at location **D**. When reducing the blank holding force and analyzing results, it was found that the strain rate decreased at positions **A** and **B** and that the strain rate increased at locations of **A** and **D** as the inflow of the material became smooth.

According to the results of the fourth analysis, no cracks occurred over the surface of the product, once again. In the

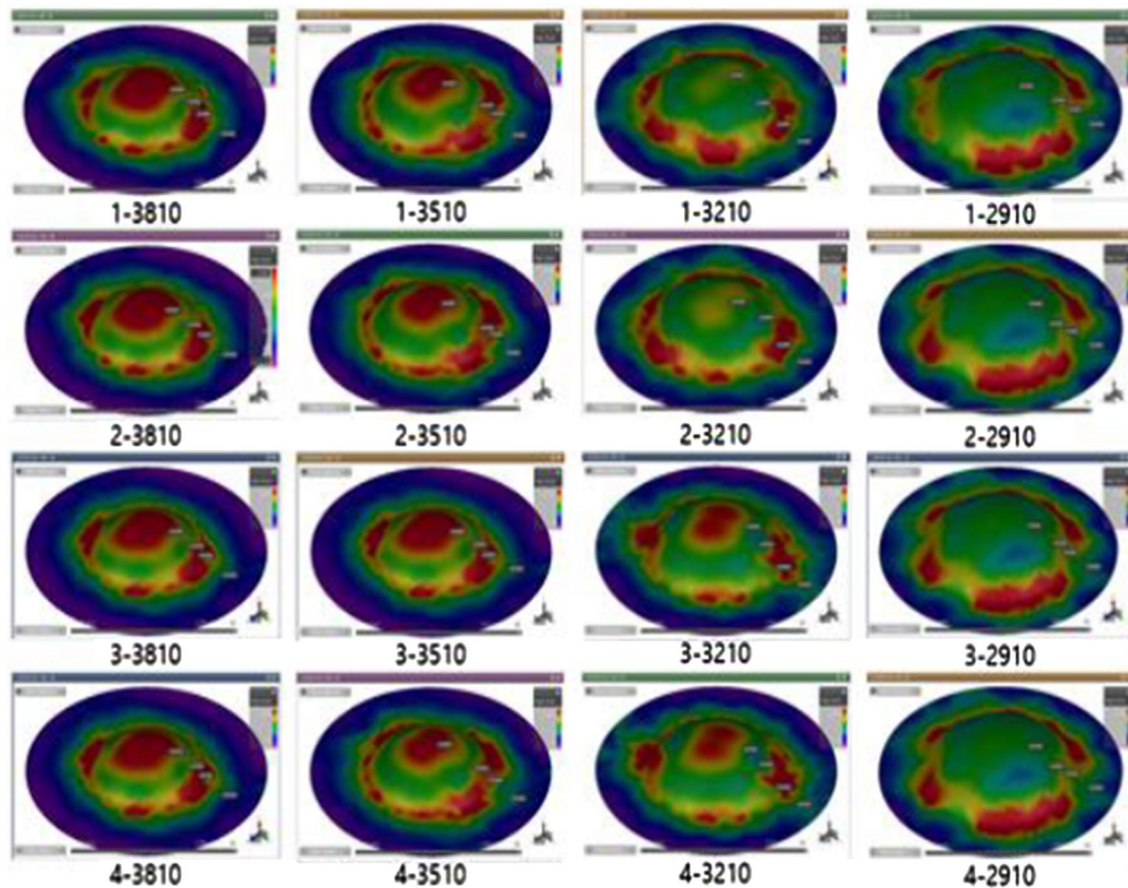


Fig. 5 Images of drawing product analysis results

Table 4 Parameters used in the analysis

Parameter	Value	Unit
Tool movement	10	m/min
	15	
Blank holder pressure	176.5	N
	117.7	
Blank size	380	mm
	350	
	320	
	290	
Die corner radius	18	mm

4-3810 case, the thickness strain at position **A** showed a maximum of 0.055%, decreasing by 0.036% at position **B** and by 0.057% at position **C**. The thickness strain increased by 0.032% at location **D**. With an increase in the drawing speed, it was found through an analysis of the results that

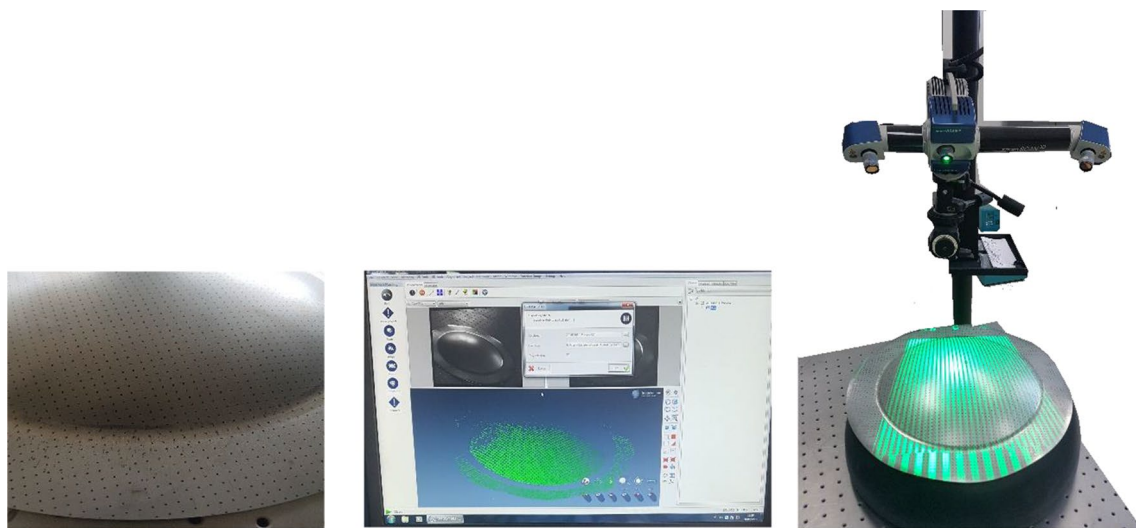
the strain rate decreased at positions **A**, **B**, and **C** and that the compressive strain rate increased as the thickness value increased at location **D** as the inflow of the material became smooth.

4 Experimental results and discussion

4.1 Experimental results

Smart SCAN 3D (resolution $1 \times 1.032 \times \text{pixel}$) was used, and the measurement principle used was the MPT (miniaturized projection technique). Three specimens were prepared for the drawing experiment, and the outer diameters of the products were measured. The average values and the outer diameters of the products generated in the analysis were compared. Figure 6 shows the product measurement process.

Table 5 shows the averages of the measured values obtained from the material inflow experiment and the data

**Fig. 6** Product measurement method**Table 5** Product outer diameter according to the experiment and the analysis results

Test order	Die parts	Experiment result (mm)	CAE Analysis result (mm)	Test order	Die parts	Experiment result (mm)	CAE Analysis result (mm)
1	1-3810	374.35	372.155	3	3-3810	373.85	371.97
	1-3510	343.32	341.5		3-3510	342.35	341.245
	1-3210	310.97	309.46		3-3210	310.15	308.785
	1-2910	276.93	278.375		3-2910	276.73	278.375
2	2-3815	374.42	372.3	4	4-3815	373.02	371.03
	2-3515	343.38	341.61		4-3515	341.85	340.395
	2-3215	311.91	309.79		4-3215	309.95	307.865
	2-2915	277.62	278.415		4-2915	276.43	277.415

Table 6 Amount of displacement of each part of the drawing product

Test order	Die parts	Experiment result (mm)				Test order	Die parts	Experiment result (mm)			
		A	B	C	D			A	B	C	D
1	1-3810	5.342	5.272	5.328	4.835	3	3-3810	5.321	5.254	5.356	4.934
	1-3510	5.311	5.259	5.305	4.820		3-3510	5.314	5.246	5.277	4.905
	1-3210	5.245	5.218	5.282	4.818		3-3210	5.248	5.205	5.261	4.896
	1-2910	5.193	5.193	5.255	4.803		3-2910	5.189	5.186	5.246	4.860
2	2-3815	5.354	5.322	5.331	4.951	4	4-3815	5.302	5.213	5.304	4.941
	2-3515	5.343	5.305	5.302	4.930		4-3515	5.296	5.162	5.272	4.924
	2-3215	5.260	5.271	5.288	4.918		4-3215	5.235	5.144	5.240	4.902
	2-2915	5.221	5.224	5.259	4.896		4-2915	5.182	5.116	5.227	4.881

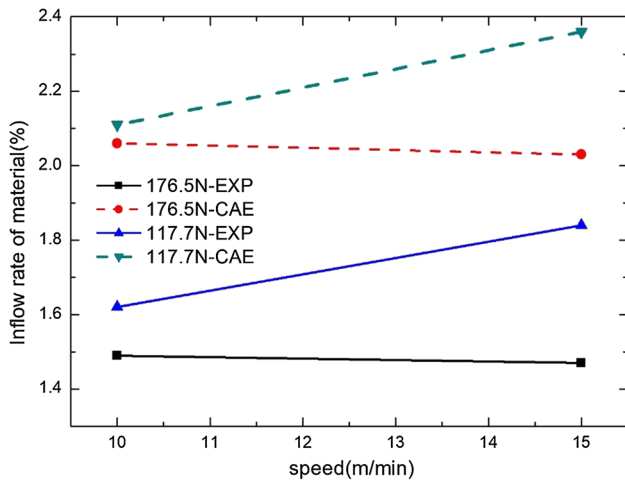


Fig. 7 Inflow rate analysis of materials in the Ø380 case

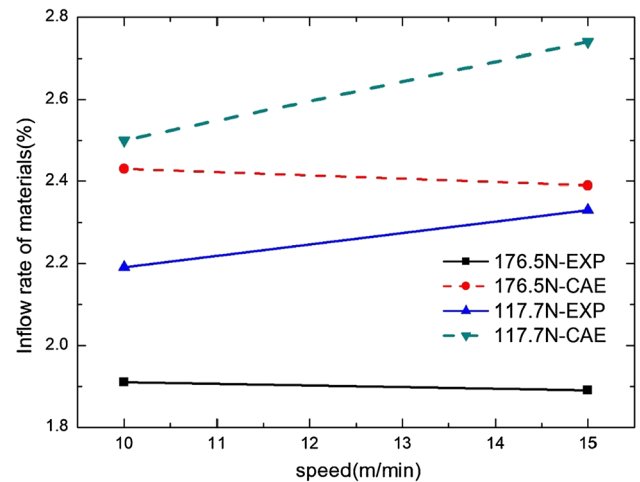


Fig. 8 Inflow rate analysis of materials in the Ø350 case

obtained from the analysis. Table 6 shows the displacement value for each position of the drawing product according to the experiment.

4.2 Analysis of experimental results

4.2.1 Experimental analysis according to the changes of the drawing speed and blank holder force

Figure 7 shows the relationship between the drawing speed and the amount of material inflow at Ø380 mm. At a holding pressure of 117.7 N, as the drawing speed is increased, the amount of material inflow increased by 11.95% and the analysis value increased by 10.59%. The experimental and analysis values showed error of about 1.36%, and both the experimental and analysis values tended to increase. At a holding pressure of 176.5 N, as the drawing speed was increased, the amount of material inflow decreased by 1.34% and the analysis value decreased by 1.45%.

The experimental and analysis values showed error of about 0.11%, and both the experimental and analysis values showed a tendency to decrease. At 117.7 N, the blank

holding force was not sufficient; this caused the inflow of the material to increase as the speed was increased, and at 176.5 N, the tension inside the material occurred as the drawing speed was increased due to the sufficient clamping force. This result showed that the inflow of the material decreases.

Figure 8 shows the relationship between the drawing speed and the amount of material inflow at Ø350 mm. At a holding pressure of 117.7 N, as the drawing speed was increased, the amount of material inflow increased by 6.00% and the analysis value increased by 8.75%. The experimental and analysis values showed error in this case of about 1.75%, and both the experimental and analysis values showed a tendency to increase. At a holding pressure of 176.5 N, as the drawing speed was increased, the amount of material inflow decreased by 1.04% and the analysis value decreased by 1.64%. The experimental and analysis values showed error of about 0.60%, and both the experimental and analysis values tended to decrease.

Figure 9 shows the relationship between the drawing speed and the amount of material inflow at Ø320 mm. At a holding pressure of 117.7 N, as the drawing speed was

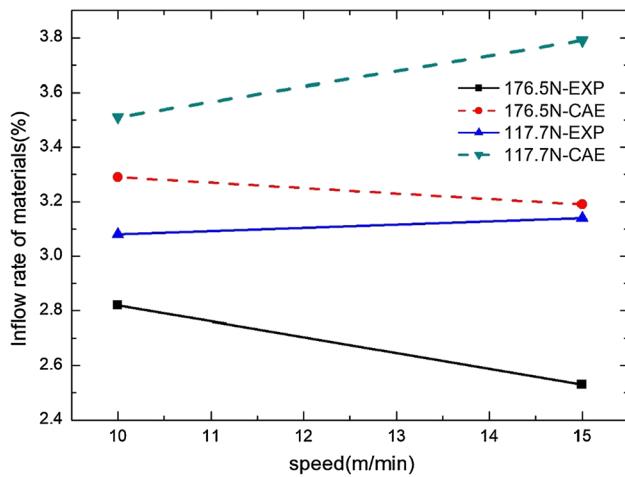


Fig. 9 Inflow rate analysis of materials in the Ø320 case

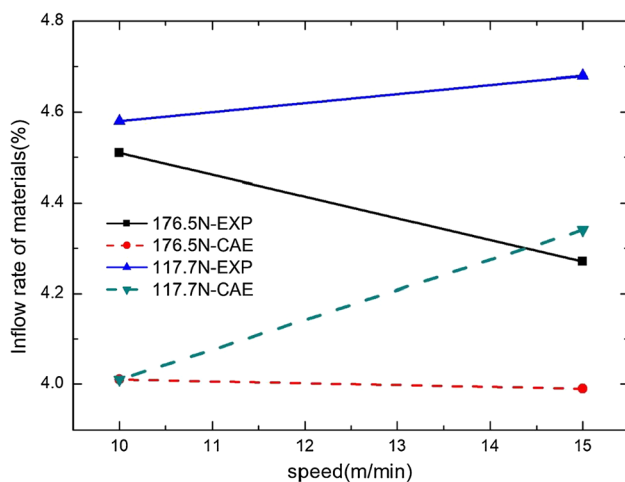


Fig. 10 Inflow rate analysis of materials in the Ø290 case

increased, the amount of material inflow increased by 1.91% and the analysis value increased by 7.38%. The experimental and analysis values showed error of about 5.47%, and both the experimental and analysis values showed a tendency to increase. At a holding pressure of 176.5 N, as the drawing speed was increased, the amount of material inflow decreased by 10.28% and the analysis value decreased by 3.03%. The experimental and analysis values showed error of approximately 7.25%, and both the experimental and analysis values showed a tendency to decrease.

Figure 10 shows the relationship between the drawing speed and the amount of material inflow at Ø290 mm. At a holding pressure of 117.7 N, as the drawing speed increased, the amount of material inflow increased by 2.13% and the analysis value increased by 7.60%. The experimental and analysis values showed error of about 5.47%, and both the experimental and analysis values

showed a tendency to increase. At a holding pressure of 176.5 N, as the drawing speed was increased, the amount of material inflow decreased by 5.32% and the analysis value decreased by 0.49%. The experimental and analysis values showed error of about 4.83%, and both the experimental and analysis values showed a tendency to decrease.

4.2.2 Analysis of tensile variation of the drawing products

The grain size is a very important factor as it affects the fatigue strength and toughness as well as the yield strength of a metallic material. In this study, the sizes of the crystal grains were measured through the line-intercept method, and the occurrence of tension and compression due to drawing displacement was analyzed.

$$D_i = \frac{l}{n_i \times M}$$

Here, the number of intersections with grain boundaries per unit length is n_i , the grain size is D_i , l is the length of the line, and M is the magnification level.

Figure 11 shows SEM images of each measurement location before and after the experiment. Ten lines of the same length were drawn in the horizontal direction, the average value was obtained by measuring the number of intersection points between the line and the grain boundary, and the size of the grain size was determined.

As a result of the analysis, the crystal grain size before the drawing was found to be 0.568 μm , and it was found to be 0.649 μm at location **A**. It was found that the grain size was stretched by 14.3% and became coarse. In addition, the crystal grain size before the drawing was found to be 0.581 μm , and it was found that the grain size was stretched by 2.3% and became coarse at location **B**. It was found to be 0.625 μm and was thought to have stretched by 10%, becoming coarse at location **C**. However, it was found to be 0.510 μm and thought to have been compressed by 10.2%, becoming dense at location **D**.

Figure 12 shows the amount of displacement at each position when the blank size is Ø380 mm. At position A, when condition 1 (with the size of the blank holder pressure being 176.5 N and the drawing speed 10 m/min) rather than the third condition (with the size of the blank holder pressure being 117.7 N and the drawing speed 10 m/min), the amount of displacement is 0.088 mm. Though this value was large, and the amount of displacement was 0.052 mm larger in condition 2 (with the size of the blank holder pressure was 176.5 N and the drawing speed 15 m/min) than in condition 4 (with the size of the blank holder pressure being 117.7 N and the drawing speed 15 m/min). It was found that

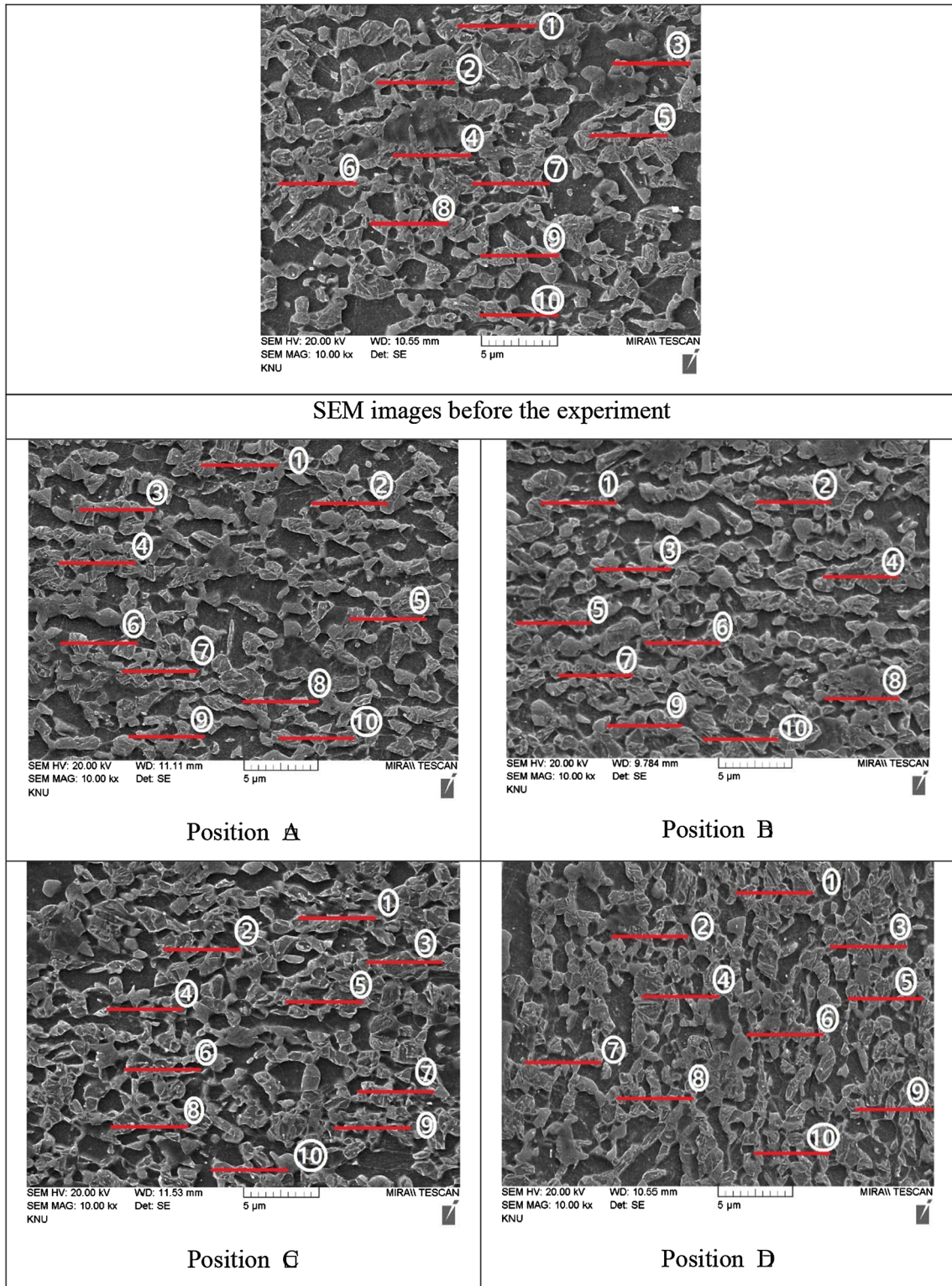


Fig. 11 SEM images of each measurement location before and after the experiment (10,000: 1)

at 176.5 N, where the pressure of the blank holder is high, the inflow of the material is effectively suppressed, causing

the amount of the tension change inside the material to increase considerably.

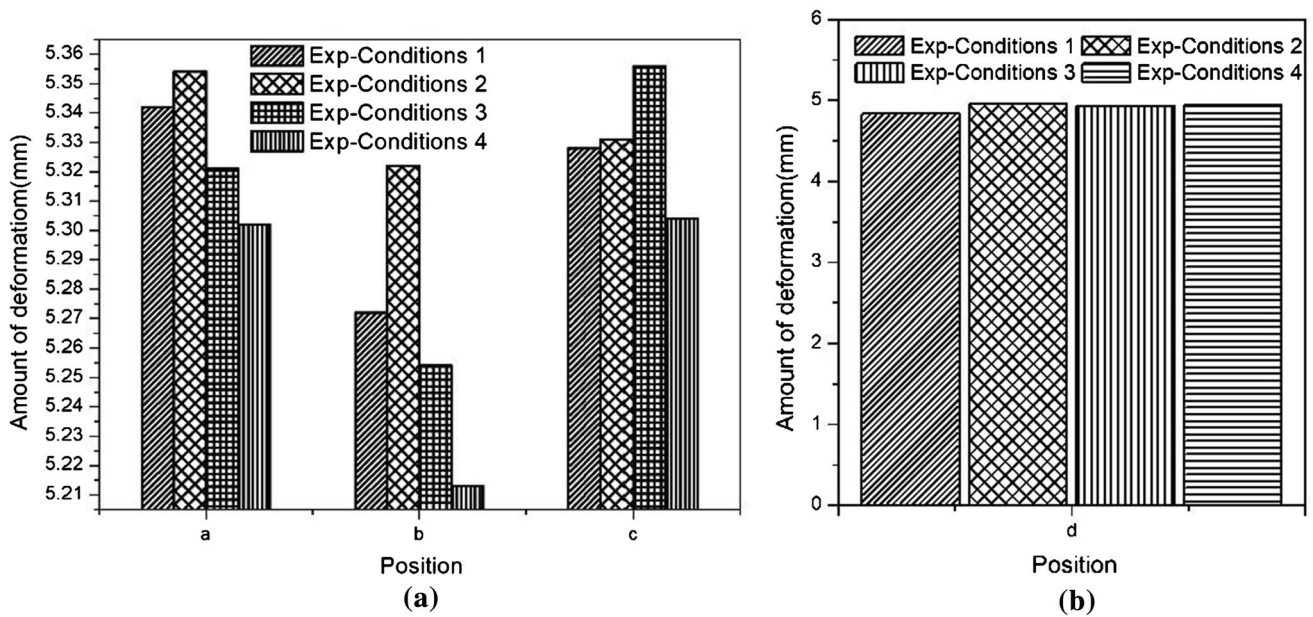


Fig. 12 Amount of displacement with the blank size of $\varnothing 380$: **a** at positions **A**, **B** and **C**; and **b** at position **D**

At position B, when condition 1 (with the size of the blank holder pressure being 176.5 N and the drawing speed 10 m/min) rather than the third condition (with the size of the blank holder pressure being 117.7 N and the drawing speed 10 m/min), the amount of displacement, at 0.018 mm, was large, though the amount of displacement was 0.109 mm larger in condition 2 (with the size of the blank holder pressure being 176.5 N and the drawing speed 15 m/min) than in condition 4 (with the size of the blank holder pressure being 117.7 N and the drawing speed 15 m/min).

At position C, the displacement amount in condition 3 (with the size of the blank holder pressure being 117.7 N and the drawing speed 10 m/min) is 0.028 mm larger than that of condition 1 (with the size of the blank holder pressure being 176.5 N and the drawing speed 10 m/min), as opposed to condition 4 (with the size of the blank holder pressure being 117.7 N and the drawing speed 15 m/min), where the amount of displacement is 0.027 mm larger in the second condition (where the size of the blank holder pressure is 176.5 N and the drawing speed is 15 m/min). As a result, it was found that the inflow of the material was suppressed and that the amount of displacement inside the material was increased at the high drawing speed of 15 m/min.

Compression displacement occurred at position D. Condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) was 0.099 mm larger in this regard than that in the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min), while the fourth condition (where the size of the blank holder pressure was 117.7 N and the drawing speed 15 m/min) was 0.01 mm larger than that of the second

condition (with the size of the blank holder pressure being 176.5 N and the drawing speed 15 m/min). In other words, it was found that at higher pressures of the blank holder and slower drawing speeds, the amount of the compression change increased.

Figure 13 shows the amount of displacement at each position when the blank size is $\varnothing 350$ mm. At position A, in condition 3 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) and condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min), there is almost no displacement (0.003 mm), and the amount of displacement was 0.047 mm larger in condition 2 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 15 m/min) than in condition 4 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 15 m/min).

At position B, when condition 1 (with the size of the blank holder pressure being 176.5 N and the drawing speed 10 m/min) rather than the third condition (with the size of the blank holder pressure being 117.7 N and the drawing speed 10 m/min) is used, the amount of displacement is 0.013, a large value, though the amount of displacement was 0.143 mm larger in condition 2 (with the size of the blank holder pressure being 176.5 N and the drawing speed 15 m/min) than in condition 4 (where the size of the blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

At position C, when condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) rather than the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) is used, the amount of displacement is

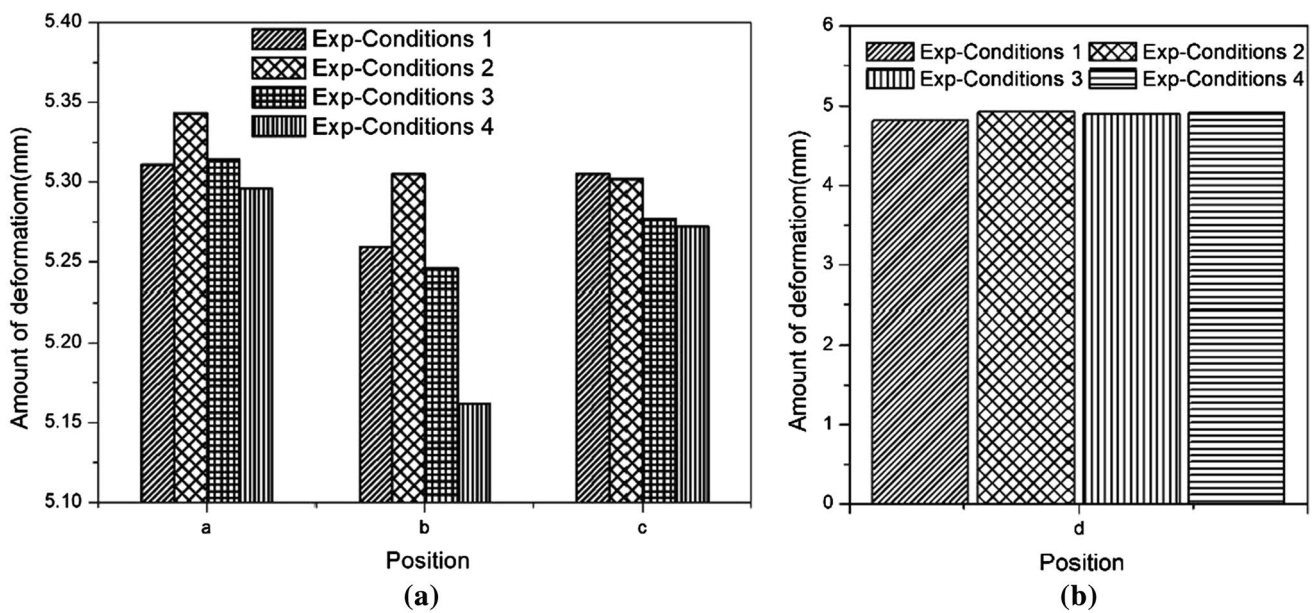


Fig. 13 Amount of displacement with a blank size of Ø350: **a** at positions **A**, **B** and **C**; and **b** at position **D**

0.028 mm, a large value, though the amount of displacement was 0.03 mm larger in condition 2 (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min) than in condition 4 (where the size of the blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

Compression displacement occurred at position D. Condition 1 (where the size of the blank holder pressure was 176.5 N and the drawing speed is 10 m/min) was 0.085 mm

larger in this regard than in the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min), while the value for the fourth condition (where the size of the blank holder pressure was 117.7 N and the drawing speed 15 m/min) was 0.006 mm larger than that of the second condition (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min).

Figure 14 shows the amount of displacement at each position when the blank size is Ø320 mm. At position A, when

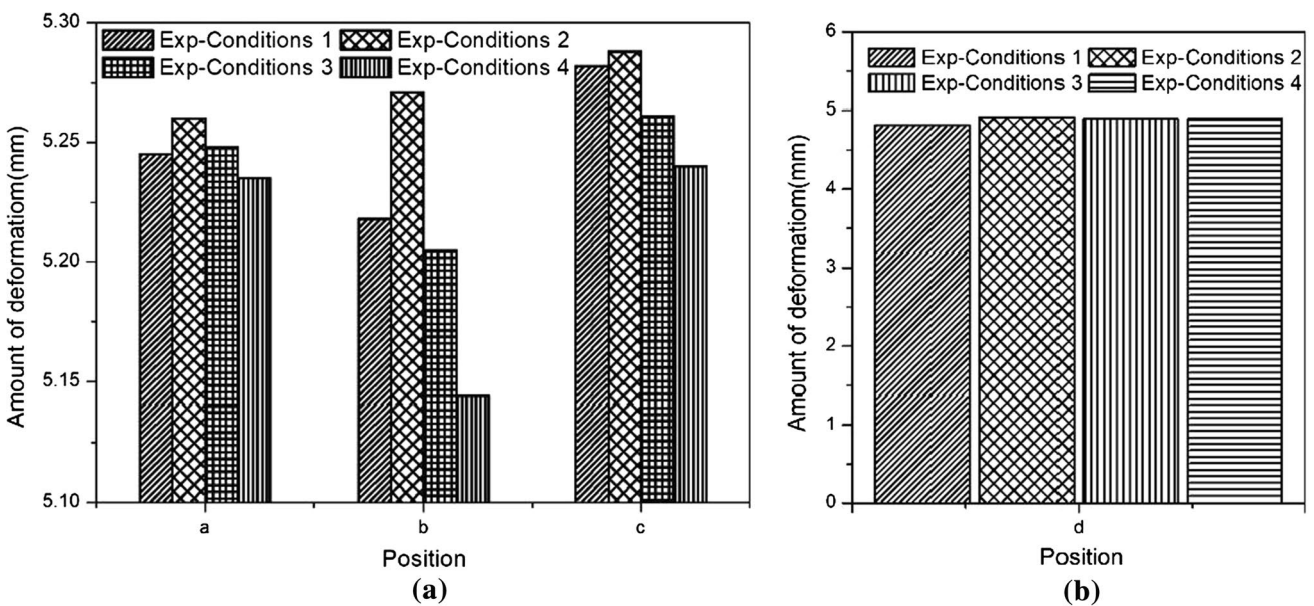


Fig. 14 Amount of displacement with the blank size of Ø320: **a** at positions **A**, **B** and **C**; and **b** and at position **D**

condition 3 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) and condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) are used, there is almost no displacement (0.003 mm), and the amount of displacement was 0.025 mm larger in condition 2 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 15 m/min) than in condition 4 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 15 m/min).

At position B, when condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) rather than the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) is used, the amount of displacement is 0.013 mm. This is large, though the amount of displacement was 0.127 mm larger in condition 2 (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min) than in condition 4 (where the size of the blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

At position C, when the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) is used rather than condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min), the amount of displacement is 0.021 mm, a large value, though the amount of displacement was 0.048 mm larger in condition 2 (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min) than in condition 4 (where the size of the

blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

Compression displacement occurred at position D. Condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) was 0.078 mm larger in this regard than the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min), while the value for the fourth condition (where the size of the blank holder pressure was 117.7 N and the drawing speed 15 m/min) was 0.016 mm larger than that of the second condition (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min).

Figure 15 shows the amount of displacement at each position when the blank size is $\varnothing 290$ mm. At position A, when condition 3 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) and condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) are used, there is almost no displacement (0.004 mm), and the amount of displacement was 0.039 mm larger in condition 2 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 15 m/min) than in condition 4 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 15 m/min).

At position B, when condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) rather than the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) is used, the amount of displacement is 0.007 mm; this is large, though the amount of displacement was 0.108 mm larger in condition 2 (where the size of the

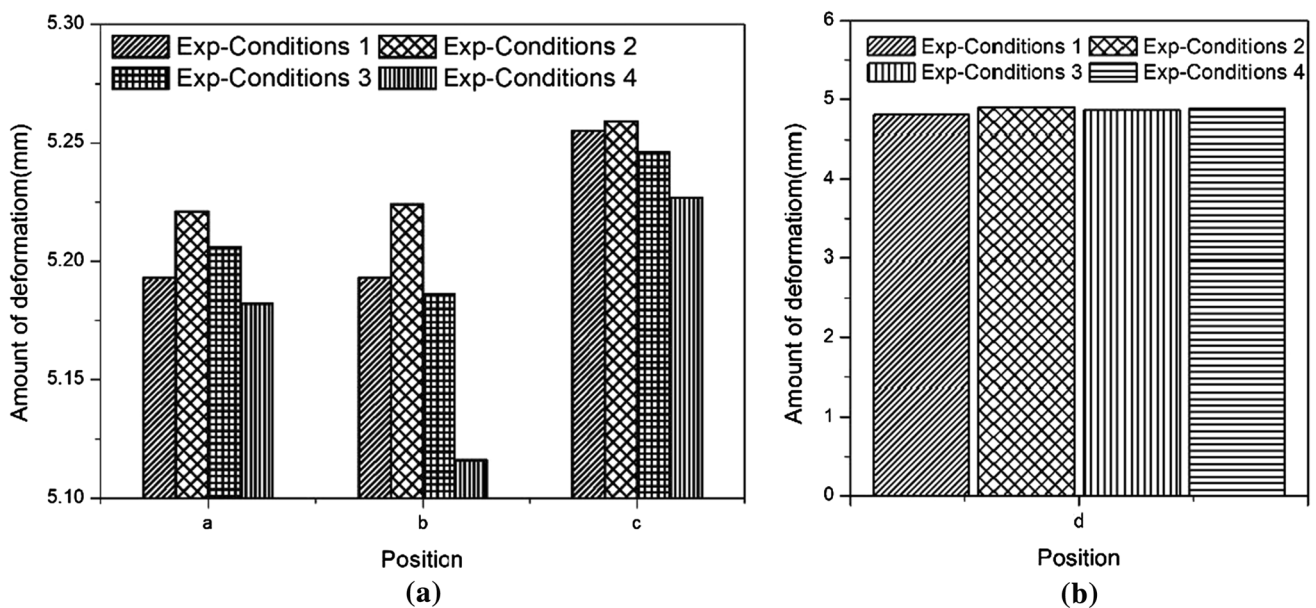


Fig. 15 Amount of displacement with the blank size $\varnothing 290$: a at positions A, B and C; and b at position D

blank holder pressure was 176.5 N and the drawing speed was 15 m/min) than in condition 4 (where the size of the blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

At position C, the amount of displacement in the third condition (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min) is 0.009 mm larger than in condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min), while the amount of displacement was 0.048 mm larger in condition 2 (where the size of the blank holder pressure was 176.5 N and the drawing speed was 15 m/min) than in condition 4 (where the size of the blank holder pressure was 117.7 N and the drawing speed was 15 m/min).

The compression displacement in condition 1 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 10 m/min) was 0.057 mm larger than that in condition 3 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 10 m/min), while the compression displacement of condition 4 (where the size of the blank holder pressure is 117.7 N and the drawing speed is 15 m/min) was 0.015 mm larger than that of condition 2 (where the size of the blank holder pressure is 176.5 N and the drawing speed is 15 m/min).

As a result of the experiment, as in the $\varnothing 380$ mm case, it was found that at higher pressures of the blank holder and slower drawing speeds, the amount of compression change in the part increases more.

5 Conclusion

In this study, using a dome-shaped drawing die and while changing the size of the blank, the drawing speed and the pressure of the blank holder, and analysis and experiment were conducted, focusing on the size of the blank by dome drawing and the change of each position. The following conclusions were drawn.

- (1) As a result of the analysis conducted while changing the pressure of the blank holder to 176.5 N and at drawing speeds of 10 m/min and 15 m/min, it was found that as the drawing speed was increased, the strain rate decreased slightly at positions **A** and **B** and increased at positions **C** and **D**.
- (2) As a result of the analysis conducted while reducing the blank holding force to 117.7 N at the drawing speed of 10 m/min and after reducing the blank holding force to 176.5 N, it was found that the inflow of the material was smooth, the strain rate decreased at positions **A** and **B**, and the strain rate was increased by increasing the frictional force of the die at locations **C** and **D**.

- (3) When 117.7 N of holding pressure was applied to the blank sizes of $\varnothing 380$ mm, $\varnothing 350$ mm, $\varnothing 330$ mm, and $\varnothing 290$ mm, as the drawing speed was increased, the inflow amount of the material increased, and when 176.5 N of holding pressure was applied, as the drawing speed increased, the inflow amount of the material decreased.
- (4) In the blank $\varnothing 380$ mm case, at positions **A**, **B**, and **C**, when the drawing speed was 10 m/min and the pressure of the blank holder was 176.5 N, the amount of displacement was large. In addition, it was found that at higher pressures of the blank holder and slower drawing speeds, the amount of compression change in the **D** part increased.
- (5) In the blank $\varnothing 350$ mm and $\varnothing 320$ mm cases, at position **A**, as a result of testing with a drawing speed of 10 m/min and at applied pressures of the blank holder of 176.5 N and 117.7 N, there was little difference in the amount of displacement. At positions **B** and **C**, when the pressure of the blank holder was 176.5 N and the drawing speed was 10 m/min, the amount of displacement was large.
- (6) In the blank $\varnothing 290$ mm case, at positions **A**, **B**, and **C**, as a result of testing with a drawing speed of 10 m/min and applied pressures of the blank holder of 176.5 N and 117.7 N, there was little difference in the amount of displacement, and it was found that at higher pressures of the blank holder and slower drawing speeds, the amount of compression change at part **D** increased.

In this study, research was conducted on the displacement of a dome-shaped drawing of the SGAF 980 material, and the demand for high-tensile steel, with levels higher than the current stiffness, will increase in order to maintain the weight and rigidity of vehicles. Therefore, it is considered that research in this area should be continued.

Acknowledgements “This work was supported by the research grant of the Kongju National University in 2019.”

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