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*Original Article*

# Process Parameter Design of Vertex Barfor Earing Defectin Deep Drawing Process Using Taguchi Technique

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***Abstract*** *- Deep-drawn parts have complex shapes and require high precision. It is required to create high-precision parts. Particularly, it is important to reduce earing defects at the tip of the deep-drawing part. The design of appropriate process parameters was considered. In this study, process parameters, including the slot angle (θ), slot width ($W_s$), and groove height (H), were investigated on a cylindrical part. The Finite-Element Method (FEM) was used to predict the bearing height. Taguchi and Analysis of Variance (ANOVA) techniques were used to investigate the degree of importance of the vertex bar parameters in the deep drawing process. The degrees of importance demonstrated that process parameters in the cylindrical deep drawing process affected the earing defect height. The degrees of importance indicate that the process parameters in deep drawing depend on the material flow mechanism. The slot angle had a major influence on the error defect at 0° with respect to the rolling direction. In contrast, the groove height had a major influence on earing defects at 90° with respect to the rolling direction. In addition to identifying the most important variables in the process by combining the FEM simulation, Taguchi technique, and ANOVA technique, the results indicate appropriate parameters for this process. This study aims to examine the connection between the friction that arises during the deformation of metal and the parameters of the deep drawing process. This demonstrates how appropriate design affects the friction value.*

***Keywords*** *- Forming, Deep drawing, Finite-Element Method, Anisotropy, Vertex bar.*

## 1. Introduction

Numerous manufacturing industries require high quality and precision. Sheet metal fabrication is a key process for various industries. Parts obtained by deformation are important components of the automotive, electronics, aviation, and housing industries [1]. Cylindrical cup-shaped items are created to produce various items. It has been aimed to reduce production costs and ensure a high precision of the workpiece. The shape shave becomes more complex. Generally, a deep-sheet metal-forming process is preferred for production. The accuracy in the dimensions of the deep-drawing parts, particularly the height of the deep-drawing part, is crucial. Finite-element method (FEM) simulations and experiments were carried out to understand deep drawing features [2-12]. The FEM is used to simulate deep drawings. The formability and quality can be improved. In addition, important defects such as cracks, earing deformations of the final workpiece, and wrinkle deformations can be eliminated [2-5]. This study aimed to reduce the deformation of earings during deep drawing. This process is used in numerous industries, including the aerospace industry, electricity, automobiles, and household appliances. Complex workpieces obtained by deep drawing must have good quality and high precision with low production costs [4-8]. AA5182 and lightweight materials are increasingly used in deep drawing processes for square, circular, and complex shapes [6, 7]. A deep drawing process was developed using a draw bead design [8], the hybrid composite material of steel with a fiber reinforcement [10], and a technique for a micro-deep drawing part [12-13].In addition to square workpieces, cylindrical cup-shaped workpieces are popular in various industries. In the development of the production process, experimental methods and FEM simulations have been used [14]. Fractures, earing deformations, and wrinkle deformations are important defects. They must be prevented so as not to cause errors. The multi-draw radius design and zoning lubricant die application were used to increase the effect of the limit drawing ratio [14]. This has been validated in several studies. The deformation of the deep-drawing model is the reason for the occurrence of the flank wrinkle technique model. In this regard, the macro texture blank holder has been designed. Buckling behaviour results have been presented [16**,** 17]. The friction coefficient is the most important parameter for the deformation behaviour in the deep drawing process. A large friction coefficient causes a fracture deformation in the punch radius region. An unbalanced friction coefficient results in a deformation of the earing defect. Lubricant techniques have been used to decrease friction in numerous studies [14, 15, 18]. Various techniques have been used with die design and blank holders, including the multi-draw radius design and macro-and microstructure tools [19]. In this study, the degree of importance of process parameters in relation to the earing defect, including the slot angle ($\theta$), slot width($W_s$), and groove height ($H$), was evaluated by Taguchi and Analysis of Variance (ANOVA) techniques [20-23]. The commercial software AutoForm R10 (C. Meicher & Co. (Thailand) Ltd.) was used for FE simulations to predict the earing defect height. The process parameters were specified by the ANOVA technique, which markedly influenced the material flow characteristics and anisotropic properties regarding the degree of importance of each deep drawing process parameter for the earing defect.

The calculation results show the importance of each deep-drag process parameter for the earing defect height. The slot angle and groove height have a major influence on earing defects. At 0°and 90° with respect to the rolling direction, θ has a major influence on the earing defect. The second and third factors are Ws and H, respectively. At 45° with respect to the rolling direction, H has a major influence on earing defects. The second and third factors are θ and Ws, respectively. The process parameters exhibited major differences in their influences on the earing defect in the deep drawing process, which could be identified based on the material flow analysis. Therefore, deep-drawing parts without earing defects can be achieved by optimal values of the parameters.

## 2. FEM and TAGUCHI Method

### 2.1. FEM Simulation

Figure 1 shows the FEM simulation model. The material flow behavior is important in the design of a vertex bar tool. The configuration of the simulation program was as follows. The workpiece was defined as elastic-plastic, while the punch, die, and blank holder were defined as rigid. The shape of the element was triangular, shell-type, and with three nodes, while the number of elements was approximately 3700.

Important parameters for the material flow mechanism are the groove height ($H$), radius ($R$), slot width ($W_s$), and groove width ($w$), as shown in Figure 1. By setting the parameters for the simulation, the test specimen was defined as a Japanese Industrial Standards (JIS)medium-carbon steel (SPCC) with a thickness of 0.5mm. Structural equations are included for the basic mechanical properties of the materials. The Poisson's ratio was 0.33, the elongation was 51%, Young's modulus was 208GPa, and the ultimate tensile strength was 317 MPa (Table 3). Another important material property for the deep drawing process for an accurate FE simulation is the plastic strain ratio (R-value) at angles of 0°, 45°, and 90° with respect to the die roll direction. In this study, the AutoForm R10 program (C. Meicher& Co. (Thailand) Ltd.) was used for the FEM. This program is suitable for deep drawing processes. The simulation requires the creation of a die, punch, and blank holder in the IGES extension, which can be achieved using the program cimatron3 (3D Systems Inc., Givat Shmuel, Israel). The friction coefficient of the standard lubricants in the deep drawing processes was 0.1. This friction coefficient is applied to the workpiece surfaces in contact with the deep drawing model (punches, dies, and blank holders).

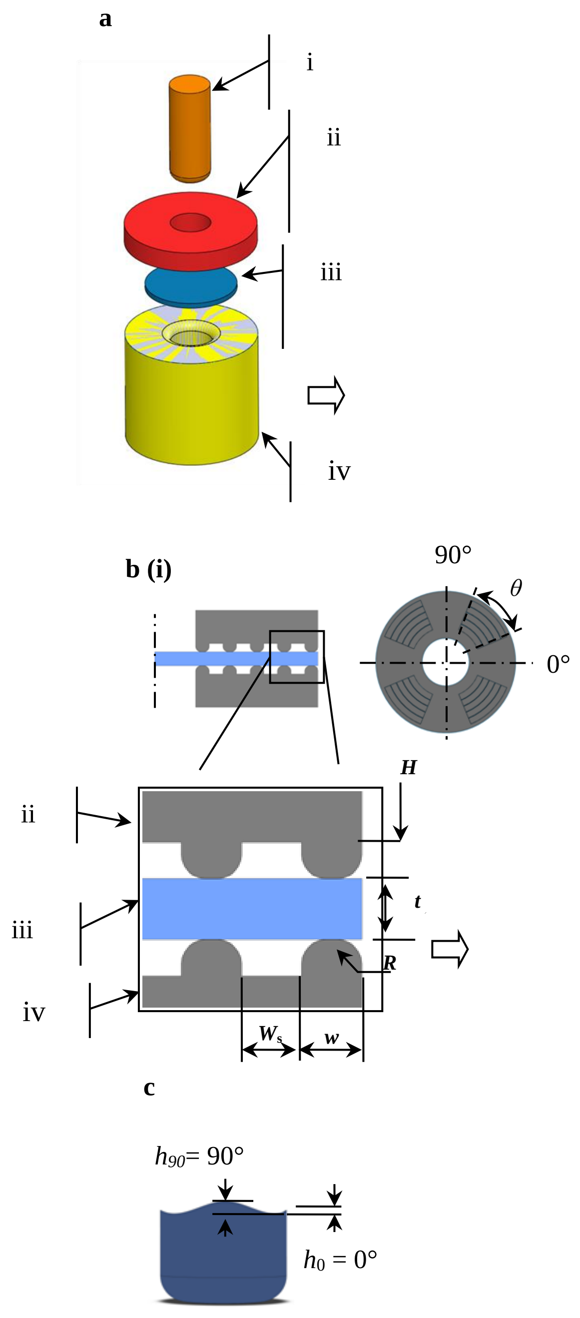


**Fig. 1 FEM simulation model**
**(a) Die position (i) Punch**
**(ii) Blank holder (iii) Initial blank (iv) Die**
**(b) (i) Vertex bar zoom (ii) Blank holder (iii) Initial blank (iv) Die**
**(H) groove height (R)radius (Ws)slot width and (w) groove width**
**(c) Final part 90° and 0° are die roll direction**

**Table 1. FEM simulation conditions**

| **Object type** | |
|---|---|
| Sheet material | elastic-plastic |
| Tool (punch, die, blankholder) | rigid |
| **Sheet material** | |
| Medium-carbon steel | SPCC, JIS |
| Thickness ($t$) | 0.5 mm |
| Ultimate tensile strength | 317 MPa |
| Young's modulus | 208 GPa |
| % elongation | 51 |
| Poisson's ratio | 0.33 |
| **Constitutive equation** | $\bar{\sigma} = 554.43\bar{\varepsilon}^{0.23} + 208$ |
| **Blank holder force** | Gap type |
| **Plastic strain ratio (*R*-value)** | |
| 0° | 2.1 |
| 45° | 1.9 |
| 90 | 2.6 |
| **Blank diameter** | 90 mm |
| **Tool geometry** | |
| Punch radius | 8 mm |
| Punch diameter | 40 mm |
| Die radius | 8 mm |
| **Friction coefficient ($\mu$)** | 0.1 |

**Table 2. Full factorial (23) experimental design for the FEM simulation**

| **Experiment no.** | **Groove height ($H$)** | **Slot width ($W_s$)** | **Slot angle ($\theta$)** |
|---|---|---|---|
| 1 | Low | Low | Low |
| 2 | High | Low | Low |
| 3 | Low | High | Low |
| 4 | High | High | Low |
| 5 | Low | Low | High |
| 6 | High | Low | High |
| 7 | Low | High | High |
| 8 | High | High | High |

Note: Groove height:0.2and 0.35 mm, slot width:5and 5.5 mm, and slotangle:30°and 45°

**Table 3. Deep drawing parameters and their levels**

| **Process parameter** | **Levels** | |
|---|---|---|
| | **Low** | **High** |
| Groove height ($H$)/(mm) | 0.2 | 0.35 |
| Slot width ($W_s$)/(mm) | 5 | 5.5 |
| Slot angle ($\theta$)/(°) | 30 | 45 |

### *2.2.Taguchi Method*

In this study, three variables of interest, the slot angle ($\theta$), slot width ($W_s$), and groove height ($H$), are divided into two levels, low and high, where the same material flow behavior occurred. The experimental design with two levels for the three-parameter full-factorial design used in the FEM simulations is presented in Table 2. The height of the earing defect is the response to the process. The most important parameters affecting the earing defect height were determined during the deep hole dragging process using the vertex bar tool. The Taguchi technique was selected due to the general trait of signal-to-noise ratio being less is better, or SNS.

$$SN_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

Where n is the number of trials and y is the process response. In addition to the FEM simulation results showing the effects of earings, the ANOVA technique was used to determine the importance of each parameter of the vertex bar tool deep drawing process, which had a clear effect on the earing defect.

## 3. Results and Discussion

### *3.1. Application of ANOVA*

Table 3 shows the process variables and low and high levels of each variable (Groove height: 0.2 and 0.35 mm, slot width: 5 and 5.5 mm, and slot angle: 30°and 45°, respectively). Table 4 lists the earing defect heights obtained using the FEM simulation program. The simulation results are consistent with the deep drawing theory, in which earing defects occur at the edge of the workpiece. In particular, earing defects at angles of 0° and 90° with respect to the die roll direction can be reduced in height using appropriate parameters. These variables affect the earing defects at different angles of 0°and 90° with respect to the die roll direction. To evaluate the significance of the process parameters, an ANOVA was performed in the case of high earing defects. Equation (1) (''smaller is better (SNs)'' characteristic) is used to carefully consider high earing defects. Equation (2) represents the mean value of the overall S/N(S=N), where k is the number of experiments. Equation (3) represents the overall mean (SS). Equation (4) represents the process parameters (SSi). Equation (5) represents the percentage contributions, which indicate the importance of each process parameter, as discussed in the next section [19]. The specified parameters are the values that result in successful forming, which are divided into 2 types: those that affect the deep draw forming of low and high friction.

$$\overline{S/N} = \frac{1}{8}\sum_{k=1}^{8}(S/N)_k \tag{2}$$

$$SS = \sum_{i=1}^{8}\left[(S/N)_{ij} - \overline{S/N}\right]^2 \tag{3}$$

$$SS_i = \sum_{j=1}^{3}\left[(S/N)_{ij} - \overline{S/N}\right]^2 \tag{4}$$

$$\%Contribution_i = \left(\frac{SS_i}{ss}\times 100\right) \tag{5}$$

Equations 1–5 can be used to determine the degrees of importance of variables as percentages, as follows. At 0° with respect to the rolling direction, θ has a major influence on the earing defect. The second and third factors are Ws and H, respectively. The corresponding percentages are 72.44%, 14.82%, and 12.74%, respectively. At 90° with respect to the rolling direction, H has a major influence on the earing defects. The second and third factors are θ and Ws, respectively. The obtained percentages are 66.66%, 19.41%, and 13.92%, respectively. The results of these calculations are presented in Table 5. The results of these statistical analyses reveal that the occurrence of earing defects depends on the selection of appropriate variables in the deep drawing process.

**Table 4. Amounts of earing defects analyzed by the FEM simulation**

| Experiment no. | Groove height ($H$/ mm) | Slot width ($W_s$/ mm) | Slot angle ($\theta$/ °) | Amount of earing defects with respect to the die roll direction (mm) | |
|---|---|---|---|---|---|
| | | | | $h_0$ = 0° | $h_{90}$ = 90° |
| 1 | 0.20 | 5.0 | 30 | 2.7 | 1.3 |
| 2 | 0.35 | 5.0 | 30 | 1.9 | 0.6 |
| 3 | 0.20 | 5.5 | 30 | 2.6 | 1.2 |
| 4 | 0.35 | 5.5 | 30 | 1.9 | 0.4 |
| 5 | 0.20 | 5.0 | 45 | 2.6 | 1.2 |
| 6 | 0.35 | 5.0 | 45 | 0.7 | 0.3 |
| 7 | 0.20 | 5.5 | 45 | 2.6 | 1.1 |
| 8 | 0.35 | 5.5 | 45 | 1.9 | 1 |

**Table 5. ANOVA results**

| Experiment no. | Groove height ($H$/ mm) | | Slot width ($W_s$/ mm) | | Slot angle ($\theta$/°) | |
|---|---|---|---|---|---|---|
| | 0.20 | 0.35 | 5.0 | 5.5 | 30 | 45 |
| **$h_0$ = 0°** | | | | | | |
| $(S/N)_{ij}$ | -1.568 | 5.713 | -1.332 | -1.875 | 2.133 | 2.012 |
| Sum of squares ($SS_i$) | 26.513 | | 36.966 | | 126.939 | |
| % contribution | 13.923 | | 19.413 | | 66.663 | |
| **$h_{90}$ = 90°** | | | | | | |
| $(S/N)_{ij}$ | -8.381 | -3.407 | -4.851 | -6.937 | -7.019 | -4.769 |
| Sum of squares ($SS_i$) | 12.373 | | 2.176 | | 2.532 | |
| % contribution | 72.437 | | 12.741 | | 14.822 | |

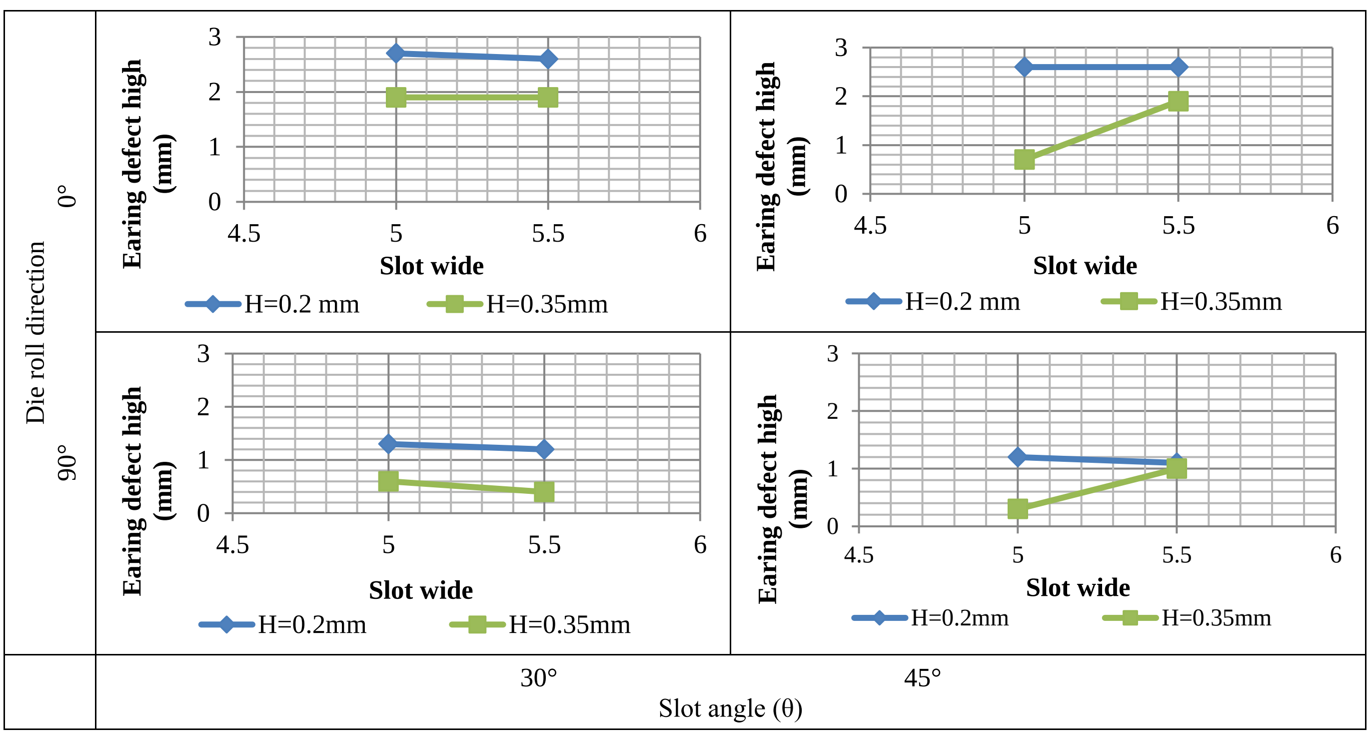


**Fig. 2 Comparison of amounts by the earing analysis by the FEM simulation with respect to the process parameters**

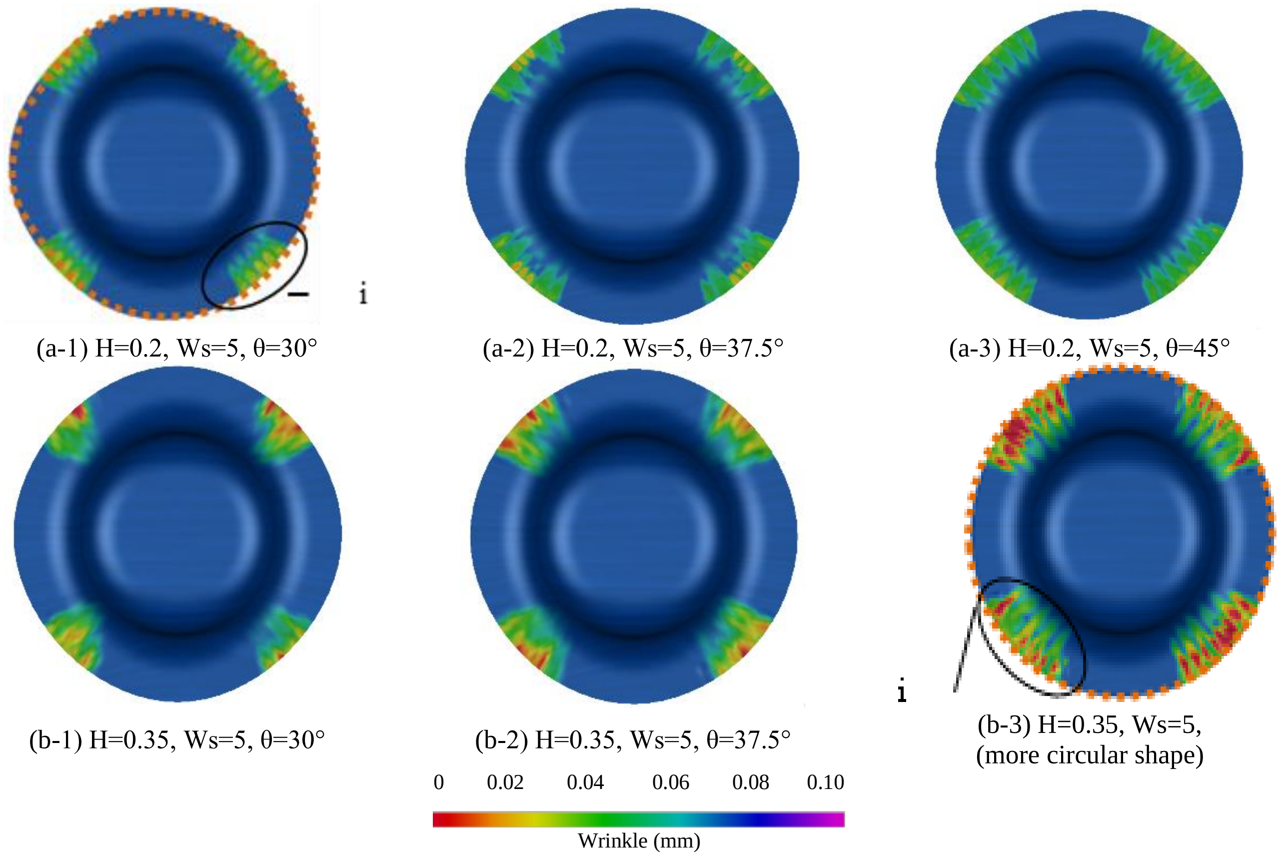


**Fig. 3 Comparison of wrinkles during deep drawing deformation according to the groove height (i) Wrinkle**

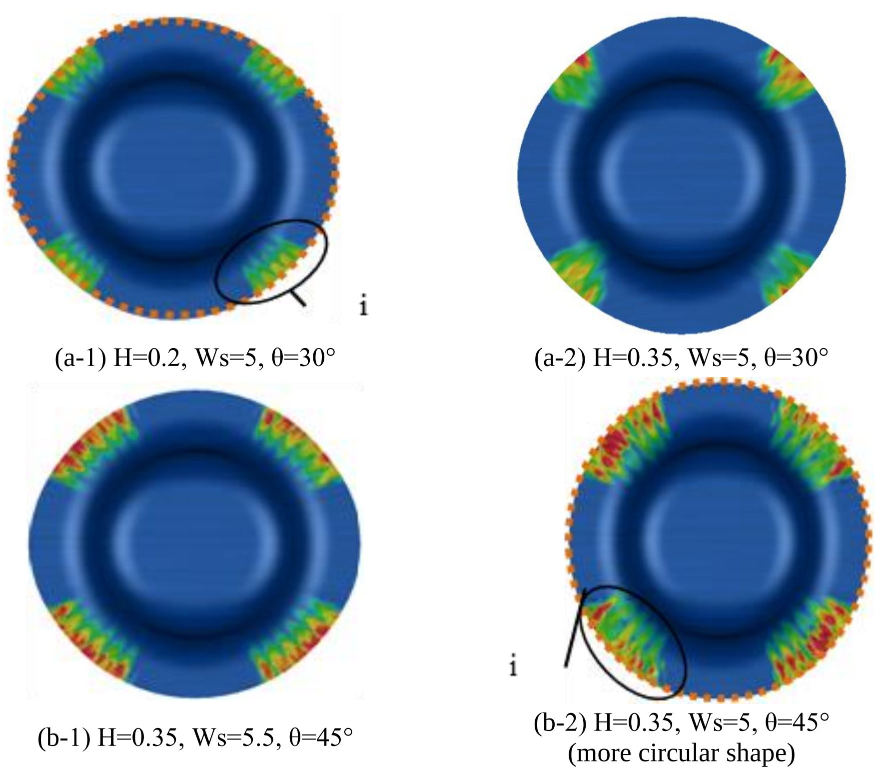


**Fig. 4 Comparison of wrinkles during deep drawing deformation according to the slot width (i) Wrinkle**

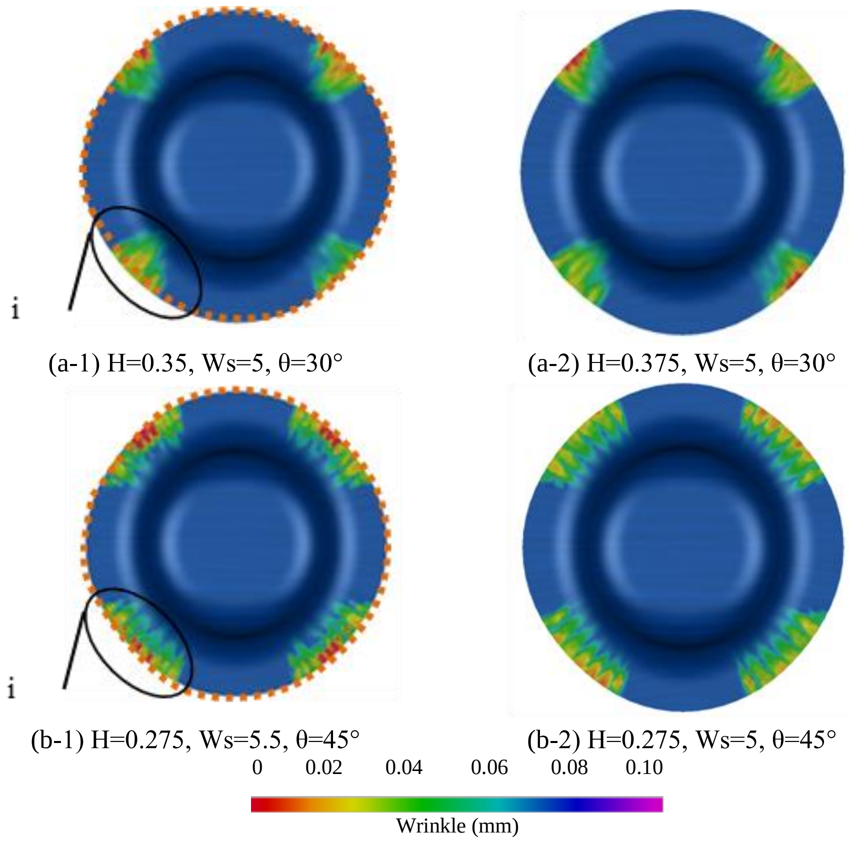


**Fig. 5 Comparison of wrinkles during deep drawing deformation with respect to the vertex bar slot angle (i) Wrinkle**

### *3.2. Effects of Process Parameters on the Earing Defects*

Variables in the deep drawing process that affect part defects have been extensively studied, including the die radius, punch radius, and blank holder force. The methods provide high-quality and -precision parts. Earing defects are widely studied deep-drawing defects. Therefore, the effects of the process parameters on earing defects in the deep drawing process should be investigated. In this study, the effects of the groove height, slot width, and slot angle on earing defects were investigated and identified based on a stress distribution analysis. Figure 2 shows the earing defect height obtained by the FEM related to the groove height, slot width, and slot angle. The results showed the same earing defect height trend for groove widths of 5 and 5.5 mm, as shown in Figure 2.

In particular, the variables affecting the height of the earing defect at angles of 0° and 90° relative to the die roll direction are different. At 0° with respect to the die roll direction, the high groove (0.2 mm) always resulted in an earing defect higher than 0.35 mm. When θ increases, the effects on the earing defect height at angles of 0°and 90° with respect to the roll direction are not different. The trends for different earing defect heights and large quantities are presented. There are few solutions to the problem of earing defects. This problem has been further. The mechanism of earing defect formation is related to the vertex bar tool of the deep drawing process parameters. The importance of each parameter in this process cannot be clearly evaluated. According to the analysis of the wrinkle of the workpiece in the flank area, the mechanism of earing defects is related to the parameters of the vertex bar tool deep drawing process. Figure 3 compares the wrinkle formation on the workpiece flange according to the groove height of the vertical bar. The simulation results show that the wrinkle height increased with the groove height. The increase in the wrinkle height at the vertex bar tool position was similar to that at the groove height. In addition, the larger slot angle detrimentally affected the material velocity of the workpiece. The flange workpiece had a more circular shape. Therefore, with these characteristics, the amount of flow increased with the slot angle of the vertex bar tool. Figure 4 compares the heights of the workpiece wrinkles according to the slot width of the vertex bar tool. The height of the workpiece wrinkle is larger at a larger width of the slot. The slot width detrimentally affects the material flow. When the number of wrinkles was high, the height of the wrinkle was large. The width of the slot is also important for the flow on the workpiece flange.

Figure 5 shows a comparison of the workpiece wrinkles and groove heights. A higher number of workpiece wrinkles were observed when the groove height was large, which is consistent with the basic theory of deep drawing [1]. The effect of the process parameters can be described in the same manner as that described above. The approach improves the workpiece flow by spreading the material around the workpiece flange in a circle. This reduces defects in the workpiece, which is consistent with these reported results[14]. Similar to these results, the effect of the process parameters and obtained results on the importance of the process parameters analyzed by the ANOVA technique can be identified based on the flange wrinkles that affect the workpiece velocity. The groove height and slot angle have a large influence on the occurrence of workpiece wrinkles at 0° and 90° with respect to the roll direction, respectively.

## 4. Conclusion

The Taguchi and ANOVA techniques were used to design simulations with the FEM to determine the importance of the vertex bar tool parameters in the deep drawing process, including the groove height, slot width, and slot angle. The ANOVA results were expressed as percentage contributions, which showed the influence of the vertex bar tool parameters on the wrinkled part formation. At 0°and 90° with respect to the rolling direction, the slot angle ($\theta$) had a major influence on the earing defect. The second and third factors were the slot width ($W_s$) and groove height ($H$), respectively. Their percentage contributions were 72.437%, 14.822%, and 12.741%, respectively. At 45° with respect to the rolling direction, the height (H) had a major influence on earing defects. The second and third factors were the slot angle ($\theta$) and slot width ($W_s$), respectively. Their percentage contributions were 66.663%, 19.412%, and 13.923%, respectively. When it comes to the deep drawing process, vertex bar tool design is the most crucial element. Only after the researcher is aware of the work variables' priority can the design be completed.

The variables have already been examined in this study. The formation of corrosion on the workpiece flange affected the material velocity in the die and significantly affected the occurrence of earing defects. The ANOVA calculations showed that the groove height and slot angle affected the earing defect at 0° and 90° with respect to the rolling direction, respectively. Therefore, the design parameters of the vertex bar tool in the deep drawing process also depended on the wrinkle height. The combined use of FEM simulation tools, the Taguchi method, and the ANOVA technique improved the performance of variable prediction. In addition to improving the quality of the earing defects, the parameters of the vertex bar tool in the deep drawing process can optimize the process parameters to reduce the earing defect height.

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