Prediction of earing in deep drawing of the cylindrical cup of stainless steel SUS304 by numerical simulation

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ABSTRACT

After the deep drawing of cup-shaped features, the product develops a "earing" due to the anisotropy of the sheet metal. Predicting the formation of "earing" during the deep drawing process is crucial for decreasing this fault. The goal of this work is to forecast the production of "earing" during the deep drawing process of a cup-shaped detail made of stainless steel SUS304 by modeling and experimental results. In a simulation employing the experimentally obtained anisotropy coefficients of stainless steel SUS304, the Barlat 89 yield criteria was used. The findings demonstrate parallels in the creation of the "earing" and demonstrate that the Barlat 89 model may be used to anticipate it.

Keywords: Anisotropy; Earing; Deep drawing; Barlat 89 yield criterion; Stainless steel.

1. INTRODUCTION

The manufacturing of household items, the automobile industry, the aircraft industry, shipbuilding industry, and the defense industry are just a few industries that frequently use the deep drawing sheet metal forming technique. It is capable of producing high-quality goods with intricate shapes, exact measurements, and advantageous mechanical characteristics. However, design engineers frequently assume sheet materials to be isotropic when calculating the deep drawing technology without fully considering its anisotropy [1, 2, 4]. Due to the substantial cutting leftovers, this may result in dimensional errors and material waste. Design estimates that fail to account for anisotropy may result in a product that is too small and results in significant waste during the production of tools and dies. In the meanwhile, producing tools and dies is highly expensive. The manufacturing details employed, particularly in the defense industry, have high technical standards. As a result of anisotropy's influence, the details tend to thin out, failing to meet the requirements and producing waste products that, if used, might make battle and training more dangerous.

Isotropic material *Anisotropic material*

Figure 1. *Products of the deep drawing process.*

Scientists have investigated and suggested yield requirements for anisotropic materials, such as Von Mises's proposal for anisotropic single-crystal, in order to reduce waste and enhance product quality during the deep drawing process [3, 4]. Based on Von Mises's idea and supposing that anisotropic materials contain three symmetrical isotropic planes, Hill suggested a new yield criterion for such materials in 1948. He then continued to improve this yield criteria in 1979, 1990 and 1993. Around that time, In 1989, Barlat also proposed an yield criteria for anisotropic materials based on the Hosford criterion [6]. The authors' studies show that the mechanical properties of the materials in different directions will be different. The change in plastic deformation capacity in different directions compared to the rolling direction is characterized by the Lankford anisotropy coefficient, determined by the formula [1, 4, 5]:

$$r = \frac{\varepsilon_{22}}{\varepsilon_{33}} = \frac{\ln\frac{w}{w_0}}{\ln\frac{t}{t_0}} \tag{1}$$

Where: ε_{22} - 2 directional relative deformation;

ε_{32} - 3 directional relative deformation;

w_0, l_0, t_0 - Width, length and thickness of initial samples;

w, l, t - Width, length and thickness of deformated samples.

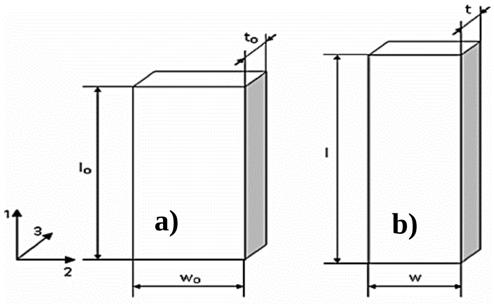


Figure 2. *Initial samples (a), and deformated samples (b).*

On the other hand, according to the law of conservation of volume, there are:

$$\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33} = 0 \tag{2}$$

Derived from:

$$r = -\frac{\varepsilon_{22}}{\varepsilon_{11} + \varepsilon_{33}} = -\frac{\ln\frac{w}{w_0}}{\ln\frac{l}{l_0} + \ln\frac{w}{w_0}} = \frac{\ln\frac{w}{w_0}}{\ln\frac{l_0 w_0}{l w}} \tag{3}$$

Due to the texture material, the load bearing capacity and deformation in the directions are different for the rolled sheet blanks used in deep drawing process, or the value of the anisotropy coefficient r will be different in the directions. It is common to consider the values of the anisotropy coefficients in the directions 0^0 (r_0), 45^0 (r_{45}) và 90^0 (r_{90}). However, to simplify the calculation process for the deep drawing problem, the values are replaced by the average value [5, 6]:

$$\bar{r} = \frac{r_0 + 2.r_{45} + r_{90}}{4} \tag{4}$$

The higher the value of the coefficient $\bar{r}$, the better the material can be drawn. Besides, the formation of ears during the claw deep drawing process is evaluated through the plane anisotropy parameter and is determined by the formula [4, 5]:

$$\Delta r = \frac{r_0 - 2.r_{45} + r_{90}}{2} \tag{5}$$

The sign of Δr represents the extent and direction of appearance of the ears. The optimal drawing capacity for each material is a combination of higher $\bar{r}$ and lower Δr values. The change of the anisotropy coefficients in the directions and the plane anisotropy parameters form 4 cases that create ears as follows [6]:

If $r_0 = r_{45} = r_{90}; \Delta r = 0$, the material is considered to be isotropic and does not form ears;

If $r_0 = r_{90}; \Delta r < 0$, four ears are formed at 450 angles to the rolling direction;

If $r_0 < r_{90}; \Delta r > 0$, four ears are formed at angles 0^0 and 90^0 with respect to the rolling direction; binaural height in the 90^0 angle direction will be larger than the 0^0 angle direction;

If $r_0 < r_{90}; \Delta r = 0$, six ears are formed with four ears in the wall at 45^0 angular directions and two ears in the 90^0 angular direction.

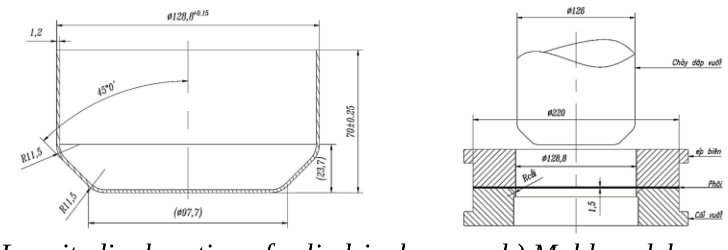
The authors have also conducted a great deal of research on the deep drawing of anisotropic materials. For instance, while drawing anisotropic materials from low carbon steel to the modification in product wall thickness, Zaky *et al.* [7] studied the optimization of the billet form. Similar to this, the Taguchi experimental model has been integrated with the works of Padmanbhan *et al*.

Izadpanad *et al.* conducted study on the creation of ears by simulating ear formation when pounding aluminum alloy AA3105 using a heterogeneous standard in Abaqus software. direction BBC2003. Through the use of Abaqus numerical simulation software, Haino Wang *et al.* [10] reexamined the potential for eight ears while deep drawing aluminum alloy 57540. These investigations, however, largely concentrate on traditional stamping steel and non-ferrous materials. Therefore, in this work, the author used numerical simulation with the Dynaform 5.9.4 software and the Barlat 89 anisotropic model to forecast the ear formation while stamping cylindrical pieces from SUS304 stainless steel material.

2. PROBLEMS

2.1. Geometric model

The die and punch system used in the simulation is assumed to be absolute rigid components. Friction between workpiece and tool is modeled by Coulomb friction model. The longitudinal section and dimensions of the cylindrical part are simulated as shown in figure 3a and the mold model structure is shown in figure 3b.



a) Longitudinal section of cylindrical. *b) Mold model.*

Figure 3. *Simulation model.*

2.2. Material and simulation conditions

The stainless steel SUS304 used in the study is the material chosen. Since this material is difficult to deform when stamped, the geometrical characteristics of the tool have a significant impact on how the material deforms. The connection between stress and strain serves as the basis for the mechanical behavior model of the SUS304 material. By cutting the sample in accordance with TCVN 197-1:2014 and performing the test, the mechanical characteristics of the SUS304 material may be entered into the simulation program. The test specimen was cut from 1.2mm thick SUS304 sheet in the directions 0^0, 45^0 and 90^0. Tensile testing was carried out on the MTS Landmark 810 mechanical testing machine with a sample tensile speed of 5 mm/min to test the specimen. until broken.

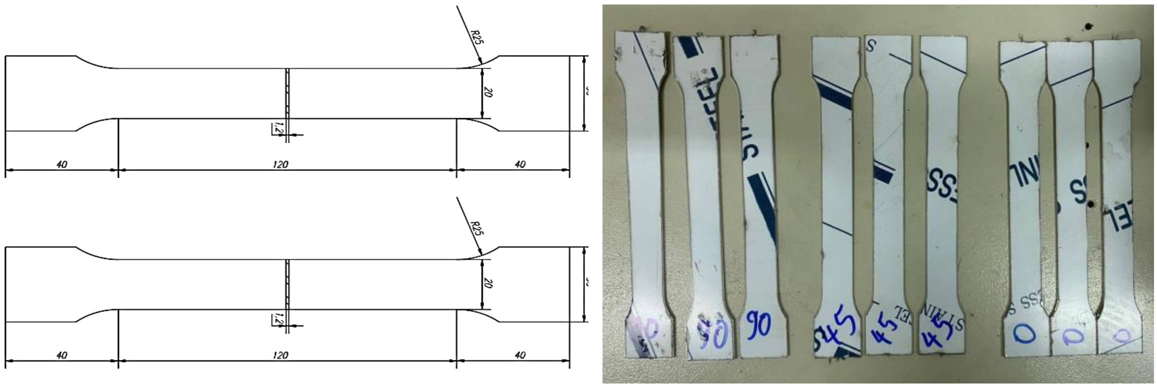


Figure 4. *Sample image of tensile test.*

The stress-strain curve of the specimen after the tensile test is reconstructed in figure 5.

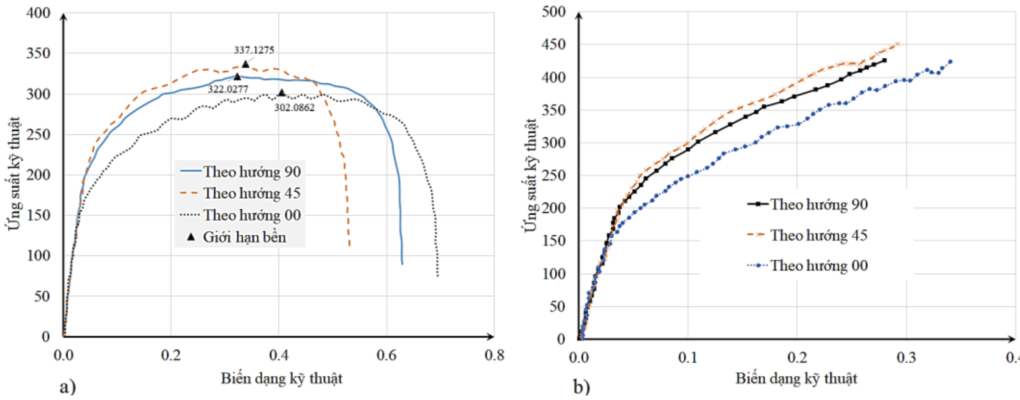


Figure 5. *Engineering stress curve (a), real stress curve (b).*

To determine the anisotropy coefficients at the angular directions 0°, 45° and 90° (r_0, r_{45}, r_{90}), perform a 10% tensile strain, measure the length and width of the specimen after deformation and determine the anisotropy coefficients in the directions. angle as shown in table 1. Import the material model with the anisotropy parameters determined above as shown in figure 6.

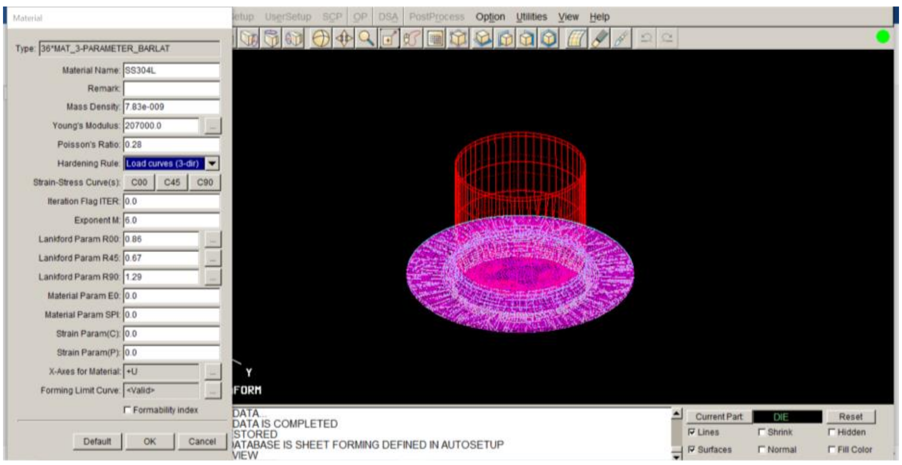


Figure 6. *Material model import for simulation problem.*

Table 1. *Anisotropy coefficient of material SUS304 in angular directions.*

Anisotropy coefficients in the directions		
r_0	r_{45}	r_{90}
0,86	0,67	1,29

3. RESULTS AND DISCUSTION

From the values of anisotropy coefficients in the angular directions as above, it can be seen that: $r_0 < r_{90}$ and $\Delta r = \dfrac{0,86 - 2.0,67 + 1,29}{2} = 0,405 > 0$. Then the product after deep drawing process is predicted to form four ears formed in the 0^0 and 90^0 angular directions relative to the rolling direction and the ear height appearing in the 90^0 angle direction tends to be the largest.

Conduct simulation according to the parameters given above, get the results as shown in figure 7.

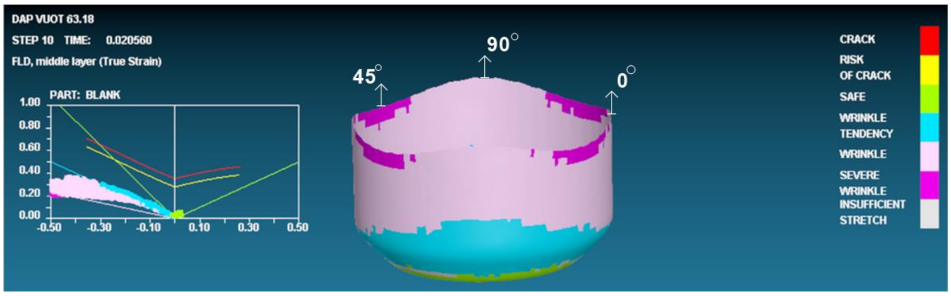


Figure 7. *Ear formation when simulated according to Barlat 89 standard.*

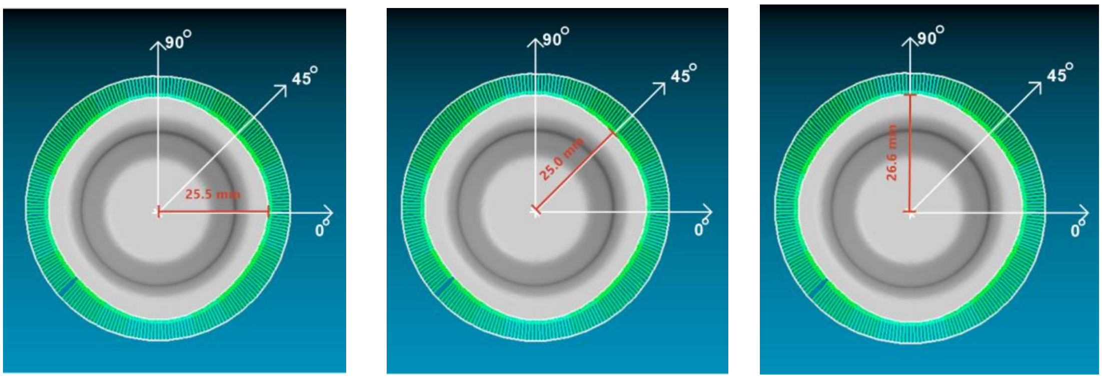


Figure 8. *Workpiece drawing process when simulated according to Barlat 89 standard.*

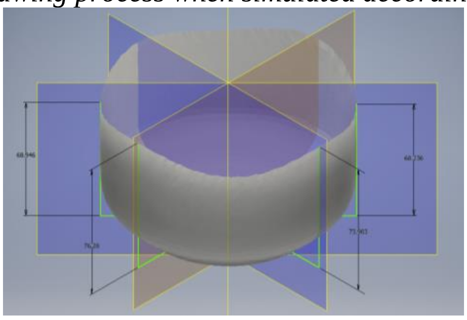


Figure 9. *Simulated posterior ear height measurement.*

After simulation, the product's ear height was measured at various angles spaced 45^0 apart (figure 9), and the findings are displayed in table 2.

Table 2. *Results of product ear height measurement after simulation.*

Corner	0°	45°	90°	135°	180°	225°	270°	315°	360°
Ear height,mm	75,2	69	76,8	69,8	75,45	69,3	76,4	70,2	75,2

From the measured results, construct the ear height change curve as shown in figure 10.

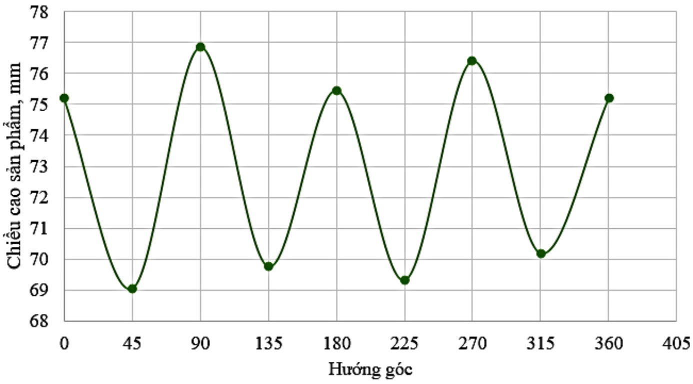


Figure 10. *Change in ear height of the product after simulation.*

The outcomes of the simulation reveal that:

- The simulation with the Barlat 89 standard-determined anisotropy coefficients depicts the emergence of 4 ears in 2 directions at angles 0^0 and 90^0. (figures 7 and 10). This outcome is highly consistent with the proposed idea.

The lowest height of the product then shows at 450 angles, being 69mm and 70mm less than the necessary height. After deep drawing process, this results in a waste product of the product.

- According to the data shown in figure 8, the embryo is most strongly drawn in the direction of angle 45^0, next in the direction of angle 0^0, and finally in the direction of angle 90^0. This demonstrates that the greatest ear's height is present. The shortest ear height now occurs at an angle of 450, which is 90^0.

The deep drawing process samples carried out experimentally using simulation results are shown in image 11.

Figure 11. *Products after stamping.*

Table 3 displays the measurement findings for the height of the ears on three representative goods. Create a graph comparing the model product with the real deep drawing process product's ear heights. Figure 12 depicts a simulated example.

Table 3. *Results of measuring the ear height of the product after stamping.*

Corner	0°	45°	90°	135°	180°	225°	270°	315°	360°
Ear height,mm	72,76	71,2	73,74	70,3	72,9	69,8	76	69,9	72,76

The result following experimental deep drawing process similarly exhibits four ears at angular directions of 0° and 90°, according to the graph in figure 12. However, the differences between the ears in simulation are not as significant or distinct as the results. In addition, the ear location is substantially taller than the other positions on the samples.

This may be explained by pointing out that the experimental procedure is to blame for a number of objective aspects, including lubrication, the placement of the workpiece, the unequal pressing pressure applied to the workpiece's surface, and the concentricity of the punch and die. Pulling the workpiece into the die cavity in a way that is unequal in all directions.

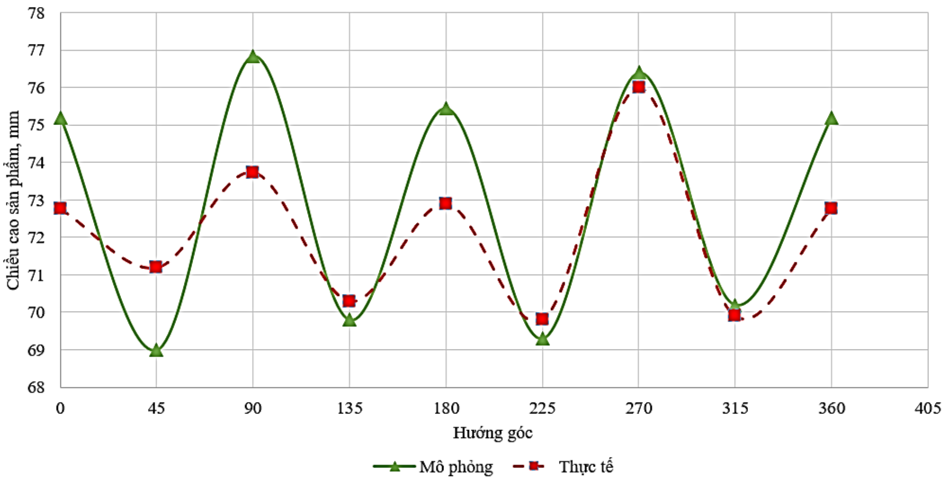


Figure 12. *Comparison between simulation and experimental results.*

4. CONCLUSIONS

It is discovered via theoretical, modeling, and experimental research that:

- An important factor in the product after drawing and a potential source of waste products is the workpiece's anisotropy.

- The formation of ears in simulation and experimental problems is basically the same and similar to the theory indicated. The occurrence of the ears occurs in the angular directions 0^o and 90^o.

- The experimental product's ear height varies from direction to direction, with one way having significantly higher ears than the others.

- The formation of ears and different heights is the basis for the technology designer to adjust the technology as well as the mold structure to be able to obtain high-quality products according to the requirements.

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TÓM TẮT

Dự đoán sự tạo thành tai khi dập vuốt chi tiết hình trụ từ thép SUS304 bằng mô phỏng số

Tính dị hướng của vật liệu dập là nguyên nhân tạo thành các "tai" của sản phẩm sau dập vuốt sâu chi tiết dạng cốc. Để tránh được các khuyết tật này thì việc dự đoán được sự hình thành các "tai" khi dập vuốt là hết sức cần thiết. Bài báo này thực hiện nghiên cứu bằng mô phỏng số và kiểm chứng bằng thực nghiệm để đưa ra dự đoán việc hình thành các "tai" trong quá trình dập vuốt sâu chi tiết dạng cốc từ thép không gỉ SUS304. Trong mô phỏng số sử dụng mô hình điều kiện dẻo Barlat 89 với các hệ số dị hướng của thép không gỉ SUS304 được xác định bằng thực nghiệm. Kết quả mô phỏng số và thực nghiệm chỉ ra sự tương đồng về sự hình thành "tai" và khẳng định rằng nó có thể được dự đoán khi sử dụng mô hình điều kiện dẻo Barlat 89.

Từ khoá: Dị hướng; "Tai"; Dập vuốt; Điều kiện dẻo Barlat 89; Thép không gỉ.