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Analyzing earing phenomenon in deep-drawing process using Simufact Forming

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--ABSTRACT--
This study focuses on the evaluation of earing in DC06 material with a material thickness of 0.85. The aim is to compare the results obtained from experimental testing with those obtained from simulation using Simufact Forming. For the experimental research, cupping test was performed on samples of DC06 material with a thickness of 0.85. The ears were measured and analyzed to determine the extent of earing at various positions on the formed components. In parallel, simulations were performed using Simufact Forming software, considering various anisotropic and strain hardening models. The simulation models were validated by comparing the predicted earing profiles with the experimental results.
Keywords – *deep drawing, DC06, earing evaluation, FEM, Simufact Forming*

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I. INTRODUCTION

Deep drawing is a metal sheet forming process used to create a three-dimensional hollow object from a sheet of metal. This process can involve either directly forming an open hollow shape or transforming an existing open hollow shape into a smaller cross-sectional shape. It is a widely used process in the industrial sector due to its efficiency. Various factors affect deep drawing, including the size of the punch and die, the shape of the blank, and the material's ability to be formed. Deep drawing is extensively used in industries such as aerospace, automotive, kitchen utensil manufacturing, and the production of cold drink cans [1], [2], [3], [4], [5].

Finding the optimal values of process parameters is crucial in minimizing manufacturing costs in sheet metal forming, specifically in the deep drawing process. To determine these optimal values, it is essential to understand how the process parameters influence the deformation behavior of the metal sheet [4], [5].

Earing, characterized by the appearance of a wavy edge at the open end of the cup, is a prevalent defect observed during the deep drawing process. Numerous research papers have been published in the past few years focusing on the investigation and analysis of earing defects [6], [7]. Describing the mathematical aspects of the deep drawing process is challenging because the material experiences varying loading conditions and complex stress distributions at different points. Typically, the input parameters for mathematical models of deep drawing are derived from simple mechanical tests like uniaxial tensile tests. With the development of computer aided engineering, numerical simulation has become widely used in the metal plastic forming process [8].

In this experiment, a cupping test was conducted on a semi-finished product with a diameter of 66 mm made from DC06 steel. The evaluated parameter was the height of the ears formed around the circumference of the blank. Subsequently, a simulation model was created to validate the experiment. The experimental results were compared using anisotropic models Hill48 and Barlat, as well as strain hardening models according to Krupkowski or Hollomon.

II. MATERIAL, MODEL AND INPUT DATA

In this experimental research, the material DC06 with the thickness of 0.85 was used. The mechanical properties (Tab. 1) of the material were obtained via a uniaxial tensile test performed on the TIRA-Test 2300 machine.

Tab. 2 Mechanical properties of DC06

RD	Rp0,2 [MPa]	Rm [MPa]	Ag [%]	A80 [%]	n [-]	r [-]	Δr [-]
0°	157	301	25.5	46.9	0.267	2.224	0.521
45°	159	302	26.5	46.0	0.256	1.552	
90°	148	298	29.4	49.8	0.265	1.921	

The chemical composition of DC06 is shown in table 3.

Tab. 4 Chemical composition of DC06

	C_{max} [%]	Mn_{max} [%]	P_{max} [%]	S_{max} [%]	Si_{max} [%]	Al_{min} [%]	Ti_{max} [%]
DC06	0.02	0.25	0.02	0.02	-	-	0.3

III. CUP TEST FOR EARING EVALUATION

To evaluate the deep drawability of experimental materials, a cupping test was performed. The test was performed to assess the formability of the experimental materials using a deep-drawing tool (Fig. 1). An evaluation criterion of this test is the height of ears on the formed cups.

Fig. 1 Deep-drawing tool for cupping test

The parameters of the deep-drawing tool are displayed in tab. 5.

Tab. 3 Parameter of the deep-drawing tool

Parameter	Value [mm]
Punch diameter	61
Die diameter	78.46
Clearance between punch and die	1.23
Punch radius	5
Die radius	5

According to the value of Δr, it is possible to determine the susceptibility of the sheetto form earing during deep drawing. Ears are formed in sheet directions in which the value of the normal anisotropy ratio Δr is maximum. If:

- Δr > 0 – ears will form in 0° and 90° direction
- Δr = 0 – ears will not form
- Δr < 0 – ears will form in 45° direction

During the cupping test, five cylindrical cups (Fig. 3) with a flat bottom were drawn, on which the height around the circumference (Fig. 2) was subsequently measured, in the 0°, 45°, and 90° directions. The value of the blank holding force was 5.2 kN.

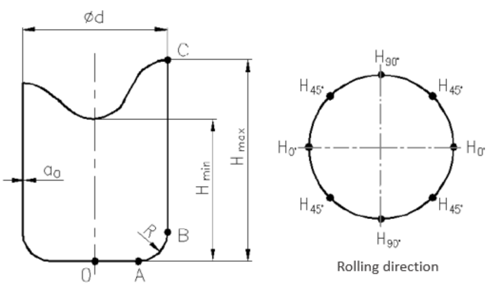

Fig. 2 Principles of earing measurement

Fig. 3 Deep-drawn cups from DC06

Measured values of ears height on five samples are shown in fig. 4.

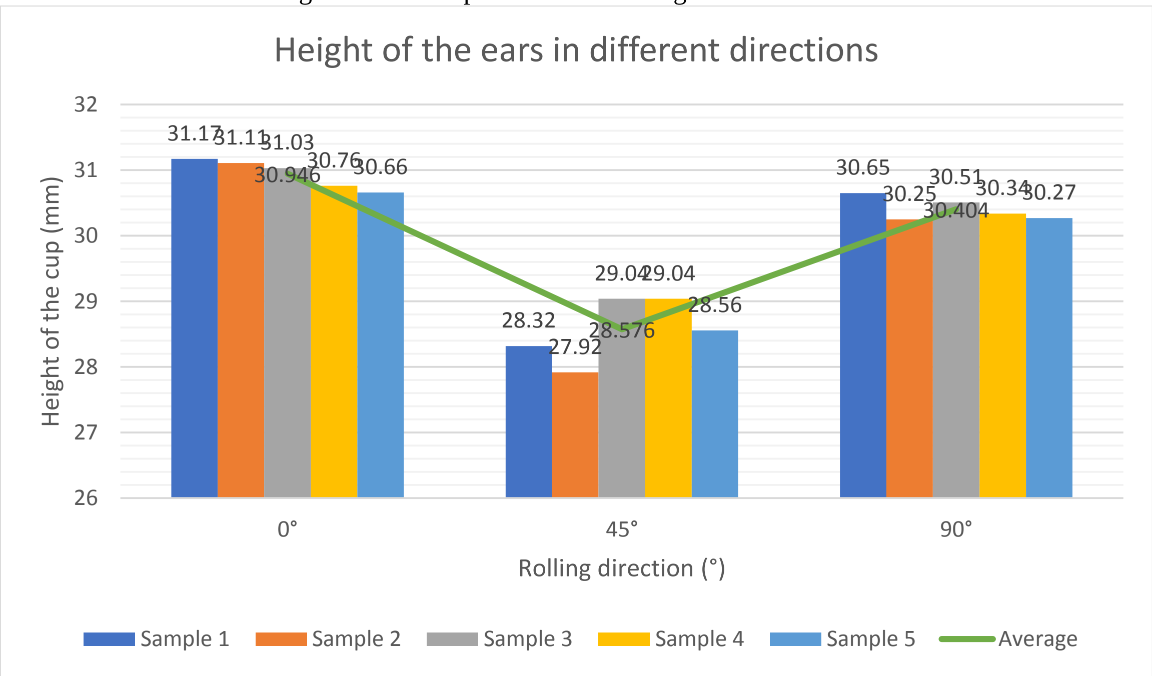

Fig. 4 Height of the ears for the experimental samples with the averague value

IV. SIMULATION

Simufact Forming software is utilized to simulate the deep drawing process of a circular cup with a diameter of 66 mm from DC06 material, employing a combination of Hill48 and Barlat anisotropic models and Hollomon and Krupkowski hardening models. The parameters of the simulation deep-drawing tool are shown in Tab. 3.

Numerical simulation was conducted with a friction coefficient of 0.05 using the Coulomb friction law. The mesh was created with hexahedral elements with a size of 0.30 mm.

According to Hu et al. [9] three layers of elements have been used through the thickness. Kura et al. [10] used five elements per thickness. More elements will bring more accurate results at the expense of computational time. In our research five elements per sheet thickness were used. If the strain limit of 0.2 is reached, the software will remesh the model.

The results of the simulation for different models of anisotropy and hardening models are shown in the fig. 5.

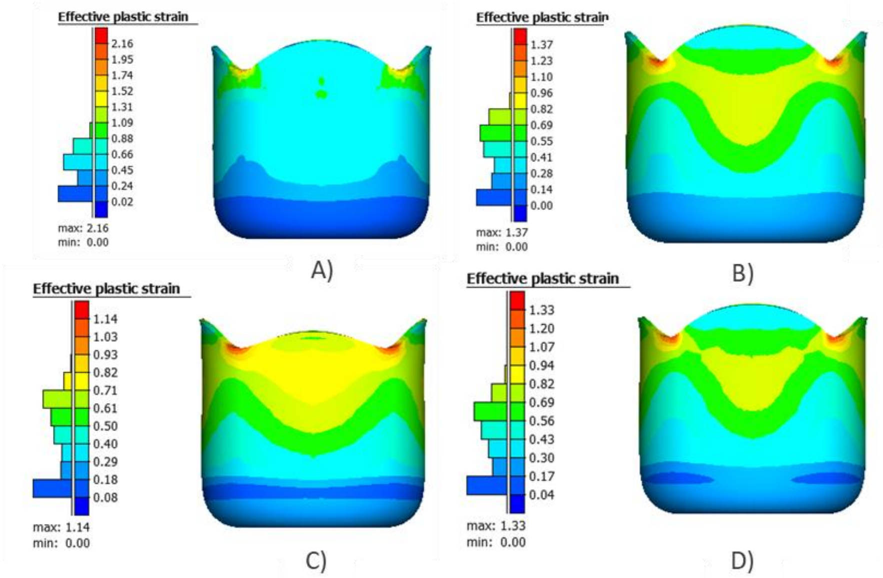

Fig. 5 Simulation results using different models A) Hill48-Hollomon, B) Hill48-Krupkowski, C) Barlat-Hollomon, D) Barlat-Krupkowski

After performing simulations using the Simufact Forming software, ear heights were measured within the software environment (Fig. 6).

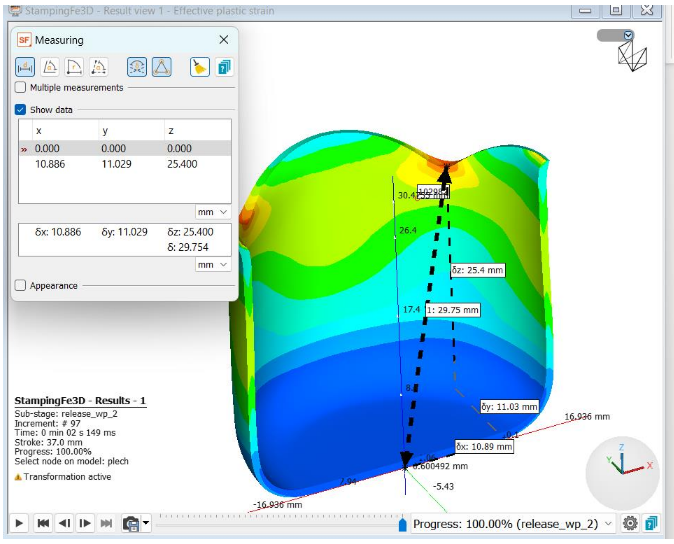

Fig. 6 Measuring of ears in Simufact Forming

The measured values of ear heights for different anisotropic and hardening models are shown in tab. 4.

Tab. 4 Ear heights for different anisotropy and hardening models

	0°	**45°**	**90°**
Hill-Hollomon	30.508 mm	26.019 mm	29.603 mm
Hill-Krupkowski	30.475 mm	25.400 mm	29.533 mm
Barlat-Hollomon	31.107 mm	26.785 mm	29.120 mm
Barlat-Krupkowski	30.963 mm	26.097 mm	29.045 mm

The graphical representation of ear heights for different anisotropy models and hardening models compared to the average ear heights on experimental samples is shown in fig. 7.

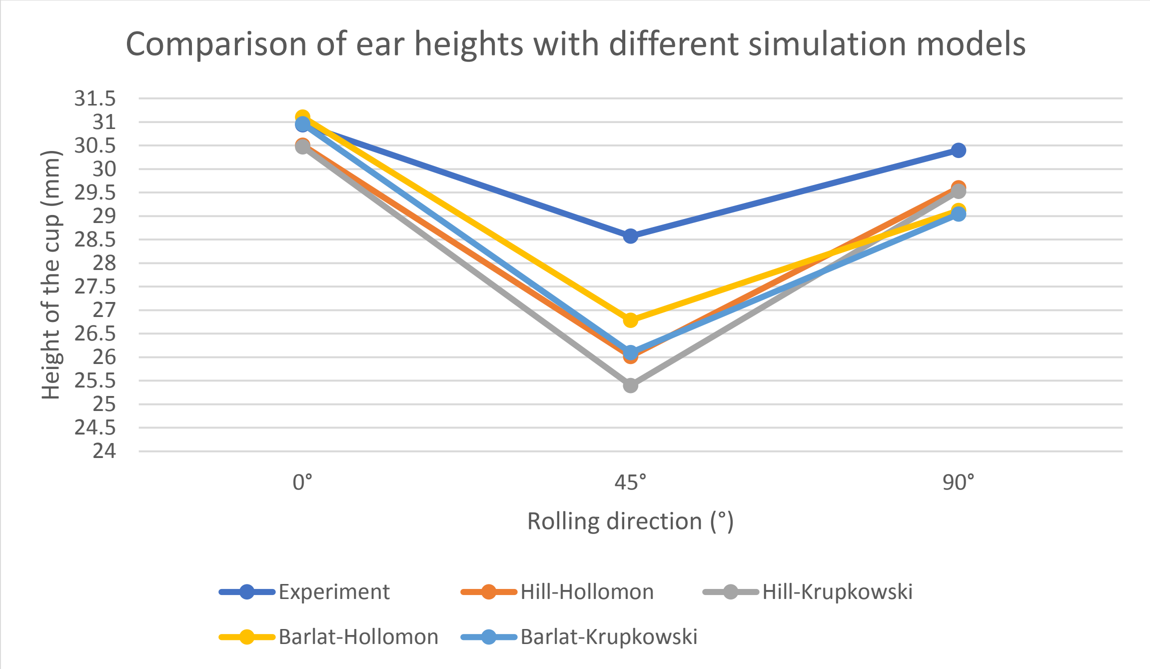

Fig. 7 Comparison of experimental results with simulation

As can be seen in the fig. 7, in the locations where ears are formed (0° and 90° relative to the rolling direction), simulations exhibit a relatively high level of accuracy with the experiment using Hill and Hollomon anisotropic models and Hollomon and Krupkowski hardening models. In the direction of 45° relative to the rolling direction, the simulation models show a lower level of accuracy. The ideal combination for the material DC06 appears to be combination of Barlat-Hollomon models, which most accurately predict the formation and size of ears during deep-drawing process.

V. CONCLUSION

In conclusion, it was noticed that earing occurred in the direction 0° and 90°. As the planar anisotropy was pos-itive the formation of earing occurred at 0° and 90° directions, which correlated with the theoretical knowledge. The maximum earing height reached a value of 31.17 mm in the cupping test for sample 1 in the 0° direction relative to the rolling direction. At 90°, the maximum measured height was 30.65 mm for sample 1. The minimum measured height of 27.92 mm was observed on sample 2.

Deep drawing simulations in the Simufact Forming software showed great accuracy in the prediction of earing. Less accuracy with the used models was recorded in the 45° direction. In this case, the simulation using a combination of Barlat-Hollomon models exhibited the highest level of agreement with the experimental results.

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