INVESTIGATING THE EFFECTS OF MATERIAL PROPERTIES, PUNCHING SPEED, AND PUNCH/DIE CLEARANCE ON STAMPING PROCESS: A NUMERICAL SIMULATION AND ANALYSIS APPROACH

Bui Long Vinh

Article History: Received: 17.03.2023 **Revised:** 01.05.2023 **Accepted:** 15.06.2023

Abstract

This research aimed to investigate the effects of material properties, punching speed, and punch/die clearance on the stamping process without using blank-holder force, in order to make informed decisions during forming process. The study utilized the ABAQUS software for numerical simulation of the sheet metal deformation process, enabling predictions of forming ability, identification of optimal solutions, and resolution of potential machining errors. By combining simulations with Taguchi's orthogonal array, the study analyzed how changes in material properties (SPCC, SUS304, AA6061), punching speed, and punch/die clearance influence the deformation of the sheet metal, with the goal of selecting appropriate parameters.

Keywords: ABAQUS; Taguchi; sheet metal, SPCC; SUS304; AA6061

School of Mechanical Engineering, Hanoi University of Science and Technology, 1A-Dai Co Viet Street, Hai Ba Trung District, Hanoi City, Vietnam, 100000

Email: Vinh.builong@hust.edu.vn

DOI: 10.31838/ecb/2023.12.s3.488

1. Introduction

The process of stamping sheets often involves various undesirable outcomes, such as wrinkles, torn products, uneven height, surface scratches, and incorrect sizing due to material elasticity [1]. To predict and prevent these plastic failure phenomena, it is crucial to employ criteria such as the Forming Limit Curve (FLC). Experimental data is typically inputted into simulation software like ABAQUS [2] to accurately model the stamping process. If the forming conditions, including material properties, punch speed, and punch clearance, are not appropriately chosen, issues such as wrinkling and tearing of the stamped details may arise. Consequently, improving the quality of the forming process requires a comprehensive investigation utilizing ABAQUS software in conjunction with Taguchi's orthogonal array method [3] to determine the optimal material properties, punch speed, and minimum punch/die clearance [4].

Previous research [5] has explored the influence of factors like die corner radius, workpiece blanking holder force, and punch-die clearance on sheet metal forming deformation. Building upon this previous work, the current study focuses on investigating the impact of material changes and punch speed in the drawing press, which were not examined in the earlier study.

The research methodology encompasses several steps: firstly, utilizing actual parameters, simulations could be conducted in the ABAQUS software to observe the part's behavior under different material conditions. Subsequently, the simulation results could be combined with using Taguchi's orthogonal array to evaluate the outcomes of the study. The ultimate goal of this research is to ensure that the stamped products meet specific technical requirements, namely: absence of defects such as wrinkles, tears, and warping; smooth and unblemished surface finish; dimensional uniformity with product thickness variation not exceeding 0.3 mm.

Materials

In this study, sheet materials with a thickness of 1mm are employed, namely SPCC, AA6061, and SUS304 (Table 1). These materials are widely used in stamping processes, particularly for shaping cylindrical cups and boxes. The stamping process for cylindrical cup details relies on the stress-strain curve and the Forming Limit Diagram (FLD) to analyze the deformation and failure characteristics of the workpiece. The stress-strain curve aids in predicting the occurrence of creasing, while the FLD provides insights into the part's breaking and tearing tendencies during stamping. Through simulation, it becomes possible to identify the technological parameters required to enhance the quality of the details.

Table 1: Properties of Materials

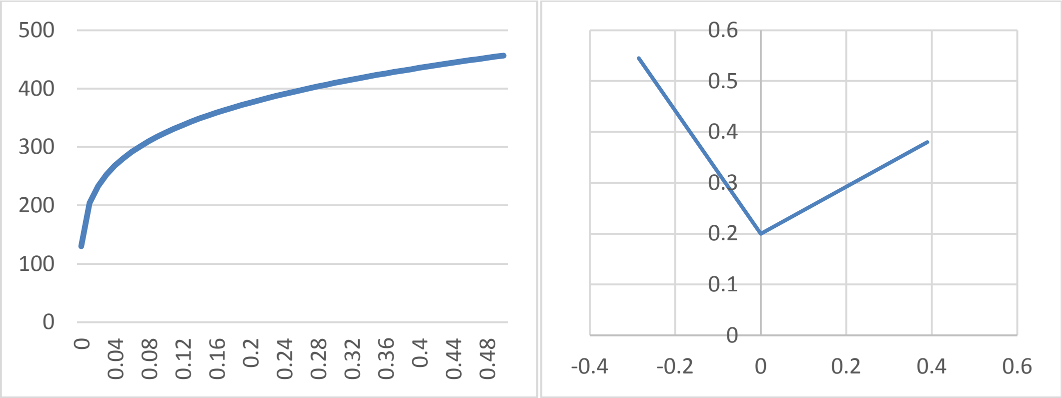
Materials	SPCC	AA6061	SUS304
Density ($\rho, kg/m3$)	7850	2700	7850
Young's Modulus (E, GPA)	210	74.6	194
Poisson's Ratio	0.3	0.314	0.26

The material curve parameters utilized in this study are derived from previously published scientific papers, ensuring reliable and established data sources. The material models are based on the yield stress curve and forming limit curve (FLC) for each respective material: SPCC (Figure 1), AA6061 (Figure 2), and SUS304 (Figure 3). The stress-strain curve equations for SPCC (1), AA6061 (2), and SUS304 (3) materials are employed in the analysis.

$$\sigma = 528.89(0.00137 + \varepsilon)^{0.213} \quad (1)$$

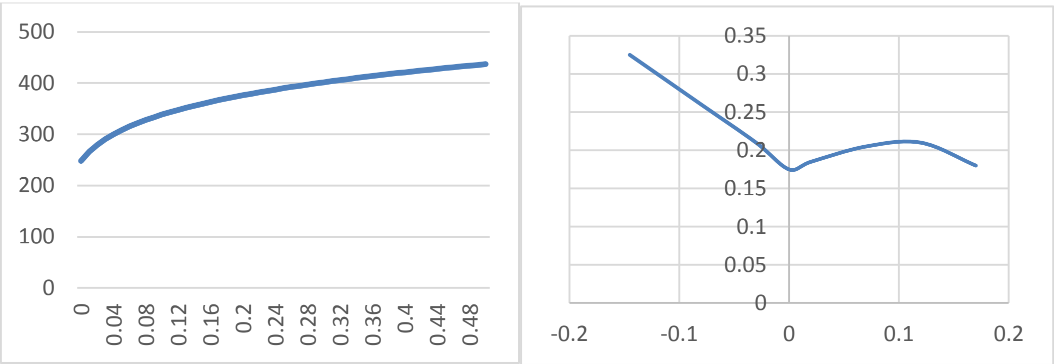
$$\sigma = 489.74(0.002 + \varepsilon)^{0.174} \quad (2)$$

$$\sigma = 188 + 50.3\varepsilon^{0.59} \quad (3)$$



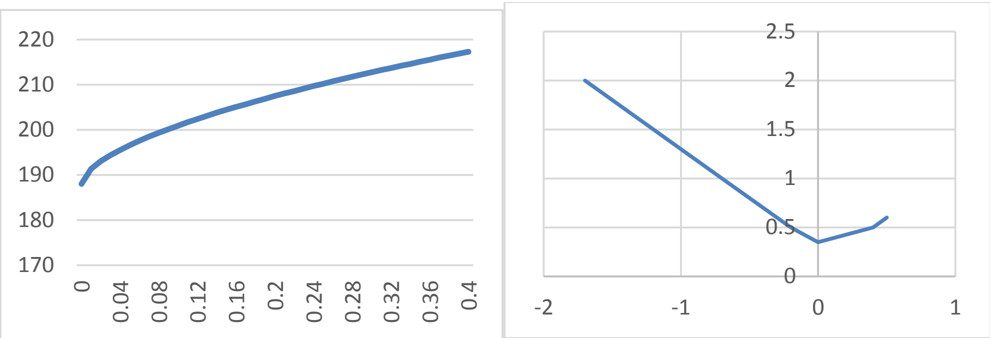
a) *b)*

Figure 1: SPCC material: a) Stress-strain curve and b) forming limit curve (FLC)



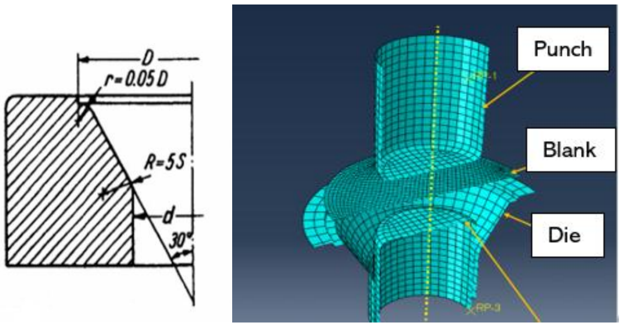
a) *b)*

Figure 2: AA6061 material: a) Stress-strain curve and b) forming limit curve (FLC)



a) b)

Figure 3: SUS304 material: a) Stress-strain curve and b) forming limit curve (FLC)



a) b)

Figure 4: Dimensions of the die (a) and FEM model (b)

The figures from 1 to 3 presented the stress-strain curves and FLD curves for each material, providing valuable visual representations of their mechanical properties. Additionally, Figure 4a displays the dimensions of the die, and Figure 4b depicts a FEM simulation of the stamping process, which could be instrumental in studying and evaluating the material behavior during the forming operations.

2. Results and Discussion

Table 2 Parameters and their corresponding levels used in the simulation process.

Parameters	Level		
	1	2	3
Material	AA6061	SPCC	SUS304
punch/die clearance (mm_	1.75	1.25	1.5
Punching speed (mm/sec)	150	200	250

In this section, the obtained results will be presented and discussed based on the simulations performed using the input conditions outlined in the previous sections. Table 2 provides the coefficients and their corresponding levels used in the simulation process. Through the application of the Taguchi orthogonal array, simulations were conducted for each case outlined in the table to predict the limits that may lead to product tearing. The simulation results, presented in the following table, indicate the destructive values of the Forming Limit Diagram (FLD) for the materials at the most critical locations. When the FLD value exceeds 1, the product is prone to wrinkles and tears. According to the Taguchi method, smaller FLD values correspond to a larger minimum part thickness after machining, indicating better forming ability for the product. Conversely, smaller values of FLDCRT (FLD criterion) indicate superior product shaping ability. The Signal-to-Noise (S/N) ratio is determined using the formula (4) provided.

$$\eta_i = -10\log_{10}[\mathrm{FLDCRT}^2] \tag{4}$$

Maximizing the S/N ratio corresponds to minimizing the plastic failure value. Simulation results revealed the occurrence of wrinkles for case 1, where the FLDCRT values exceeded 1, indicating plastic failure. Utilizing the Taguchi method, Analysis of Variance (ANOVA) is employed to describe the relationships between the parameters and the observed values of phenomena such as wrinkles and tearing. The calculated results are synthesized using the summation formula squared as shown in Eq. (5).

$$SS = 3(m_{j1}-m)^2 + 3(m_{j2}-m)^2 + 3(m_{j3}-m)^2 \tag{5}$$

Where: $m_{ji} = \frac{1}{3}\sum_{n=1}^{3}(\eta_j)_i;\ m = \frac{1}{9}\sum_{n=1}^{9}\eta_i$

ANOVA results for the fracture values (FLDCRT) presented in Table 3, corresponding to different materials, highlight that the material itself has the most significant influence on wrinkling and fracturing. The punch clearance follows as the next influential factor, and finally, the punching speed. Consequently, the punch and die clearance emerge as the most crucial parameter affecting the fracture ability during the simulation process. The material selection, in particular, plays a significant role in determining the propensity for tearing in the forming process.

Table 3: Simulation Results using Taguchi Orthogonal Arrays

stt	FLDCRT		Materials	Clearance	Punching speed	Results
	VALUE	ŋ (dB)				
1	1.487	-3.393	1	1	1	Fracture
2	2.014	-6.068	1	2	2	Fracture
3	1.854	-5.367	1	3	3	Fracture
4	1.628	-4.233	2	1	2	Fracture
5	1.545	-3.779	2	2	3	Fracture

6	1.424	-3.073	2	3	1	Fracture
7	0.549	5.209	3	1	3	Safe
8	0.734	2.686	3	2	1	Safe
9	0.5387	5.373	3	3	2	Safe

Table 4: Calculated Results

Hệ số	the average values ŋ for each level			Sum of squares	Ratios %
	1	2	3		
Materials	-4.941	-3.694	4.223	147.979	96.9%
Clearance	-0.806	-2.387	-1.0197	4.414	2.9%
Punching speed	-1.259	-1.643	-1.311	0.261	0.2%
Sum				152.645	100%

Based on the simulation process and calculations obtained using the Taguchi orthogonal array, we can analyze the influence of various factors on the wrinkling and fracuring tendencies of different materials. This analysis enables us to select the optimal parameters for the stamping process. In this case, the optimal parameters are determined to be: material of SUS 304, clearance between punch and die of 1.25mm, and operation speed of 200mm/sec. It is important to note that this specific case does not align with any of the seven simulated cases presented in Table 4. In order to validate the research, the optimal case was simulated separately, and the results for this optimal configuration are presented in Fig. 5. The maximum FLD value obtained in this case is 0.734, which is less than 1. This indicates that there are no areas of fracturing or wrinkling on the product when using the optimal parameter values. By carefully considering these simulation results and calculations, we can make informed decisions about the selection of materials and process parameters to achieve optimal results in the stamping process.

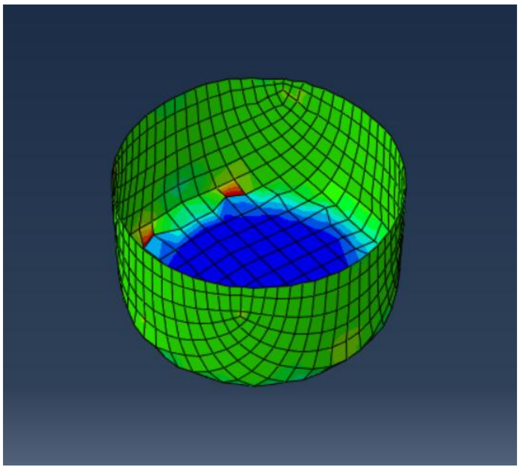


Figure 5: Safe Product with Optimal Parameter Set

3. Conclusion

Based on the simulations conducted in this study, the optimal parameters for the stamping process have been determined. Utilizing SUS 304 as the material, a clearance of 1.25mm between the punch and die, and a punching speed of 200mm/s, the optimal configuration ensures that the product meets the specified requirements. Notably, the maximum value of the FLD forming limit, which is 0.734, indicates that the product is free from wrinkles and fractures. Through the implementation of the Taguchi method and ANOVA analysis of variance, this research has successfully identified the optimal parameters for deformed parts with superior surface quality and without distortion or warping. The utilization of ABAQUS software has greatly assisted in designing the stamping die, thereby ensuring the production of high-quality parts. By employing the findings of this study, manufacturers and designers can make informed decisions regarding material selection and process parameters to achieve the best possible surface quality and prevent any defects in the final products. The combination of the Taguchi method, ANOVA analysis, and

ABAQUS software offers valuable insights for optimizing the stamping process and enhancing the overall quality of the fabricated parts.

4. References

Ikumapayi, O. M., Akinlabi, E. T., Madushele, N., & Fatoba, S. O. (2020). A brief overview of bending operation in sheet metal forming. Advances in Manufacturing Engineering, 149-159.

Hibbitt, H., Karlsson, B., & Sorensen, P. (2011). Abaqus analysis user's manual version 6.10. Dassault Systèmes Simulia Corp. Providence, RI, USA.

Taguchi, G., Japan Standard Association, Tokyo (1981).

The-Thanh, L., Tien-Long, B., The-Van, T., & Duc-Toan, N. (2019). A study on a deep-drawing process with two shaping states for a fuel-filter cup using combined simulation and experiment. Advances in Mechanical Engineering, 11(8), 1-11. doi: 10.1177/1687814019872674.

Luyen, T.-T., Pham, Q.-T., Kim, Y.-S., & Nguyen, D.-T. (2019). Application/Comparison Study of a Graphical Method of Forming Limit Curve Estimation for DP590 Steel Sheets. Journal of Korean Society of Precision Engineering, 36(9), 883-890. doi: 10.7736/kspe.2019.36.9.883.