STUDY ON INFLUENCE OF PROCESS PARAMETERS ON THE WALL THICKNESS DISTRIBUTION OF PART IN SHEET HYDROFORMING PROCESS FOR THE PARTS OF SPACE

Manh Tien Nguyen[1], Trong Tan Le[1], Van Huy Chu[1]

[1] *Faculty of Mechanical Engineering, Le Quy Don Technical University, Ha Noi, Viet Nam*

ABSTRACT

This paper presents the results of a numerical simulation study on the influence of process parameters on the deformation ability in the sheet hydroforming process for the parts of space. Deform 2D software is used in numerical simulation. Process parameters studied include forming pressure (q), radius of die (R), and speed of axial press of punch (v). Deformation ability is assessed through the degree of thinning of the wall thickness Δs (%). First, the response surface method (RSM) is performed to examine the relationship between the output and the input. Then, an analysis of variance (ANOVA) was conducted to verify the response significance and influence of the parameters. Finally, an optimization algorithm is used to determine the optimal set of process parameters. The obtained results allow analysis and selection of reasonable process parameters in the sheet hydroforming process for the parts of space, serving to manufacture complex parts for industrial applications.

Keyword: *Sheet hydroforming (SHF), Deform 2D software, Forming pressure, Radius of die, Speed of axial press, Degree of thinning of the wall thickness.*

1. INTRODUCTION

The SHF process is a method that uses a high-pressure liquid source that acts as a punch to deform the sheet workpiece according to the profile of the die. Due to the simplicity of the deformation process and the equipment used, this technology has been studied extensively in the world. This technology is widely applied to flexible production with small-scale production, one of the main applications of this technology is the aerospace industry, automobiles and motorcycles and civil products [1, 2, 3]. The SHF technology has confirmed its outstanding advantages such as increased level of drawing stamping (the level of drawing stamping is much increased compared to the conventional drawing stamping method), the ability to deform is increased, reduce the number of forming operations, increase the dimensional accuracy, product surface gloss, and reduce production costs [4, 5].

However, two main disadvantages that exist in the SHF process include [6, 7]:
The unstable flow of the workpiece flange in different parts on the edge of the part (there is a displacement of the flange). This is expressed in the form of wrinkles on one side of the billet flange due to the unevenness of the deformation resistance in the flange part, and also due to the unevenness of the friction force that occurs between the workpiece flange and the tool.
The degree of thinning of the wall thickness is too large and the unevenness along the length of the part wall is significant. These greatly reduce the quality of the stamping part and thus also indicate limited technological possibilities.

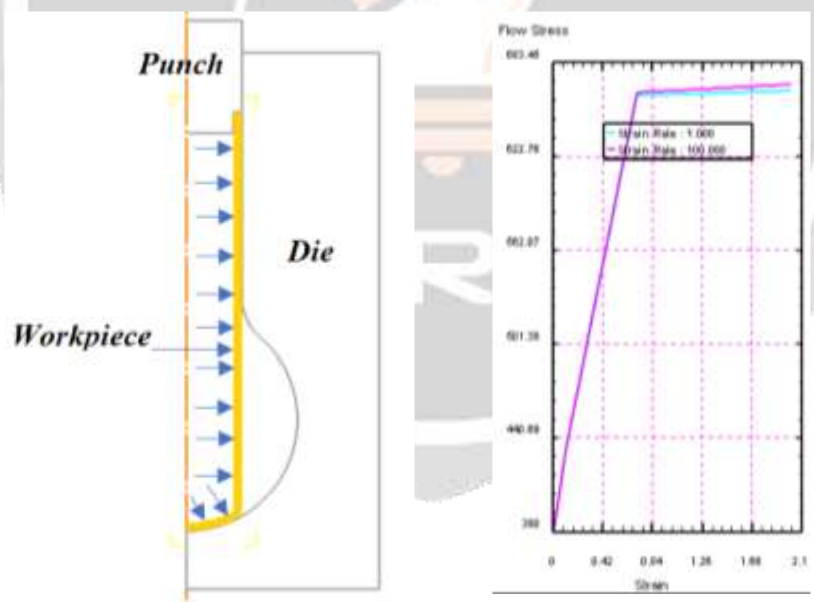
Researches on SHF technology focus on main directions including: the theory of SHF [8, 9], influence of control parameters and process parameters on deformation ability and product quality [10], stresses and strains during forming [11], failure modes and remedies during forming, improvements in forming equipment [12]… However, it is found that the object of the research is mainly the first operation, then the input workpiece is in the form of a flat sheet. Studies on SHF for the parts of space are limited.

This paper presents the results of a numerical simulation study on the influence of process parameters on the deformation ability in the SHF process for the parts of space. Deform 2D software is used in numerical simulation. Process parameters studied include forming pressure (q), radius of die (R), and speed of axial press of punch (v). Deformation ability is assessed through the degree of thinning of the wall thickness Δs (%). First, the response surface method (RSM) is performed to examine the relationship between the output and the input. Then, an analysis of variance (ANOVA) was conducted to verify the response significance and influence of the parameters. Finally, an optimization algorithm is used to determine the optimal set of process parameters. The obtained results allow analysis and selection of reasonable process parameters in the SHF process for the parts of space, serving to manufacture complex parts for industrial applications.

2. RESEARCH METHODS

2.1 Building the problem of numerical simulation of forming processes

The problem of simulating the SHF process is done on Deform 2D simulation software. The geometry model of the SHF process including a die, a space workpiece and an axially moving punch is shown in figure 1a. The workpiece has an outer diameter of Φ30 mm, and the thickness is constant along the birth line with a value of 1.5 mm. The transition radius between the cylindrical part and the hemispherical part of the die is designed with the values of 9, 12, and 15 mm, respectively. Assume that the friction between the workpiece and the tool remains constant throughout the forming process. The material model used in simulations that hardening plastic material of 1010 steel (AISI-1010,COLD[70F(20C)]) are shown in figure 1b.



a) b)

Fig - 1: The geometry model (a), the material model (b).

2.2 Studying the influence of process parameters by simulation planning

This paper aims to optimize the process parameters to reduce the degree of thinning of the wall thickness. The factors to be considered include forming pressure (q), radius of die (R), and speed of axial press of punch (v), while the objective functions are the degree of thinning of the wall thickness Δs (%).

According to table 1, the limit of factors is expressed as -1, 0, and +1 for low, medium and high values. The inputs are expressed as A for the forming pressure (MPa), B for the die radius (mm) and C for the speed of axial press of the punch (mm/s).

Table - 1: Levels and values of process parameters

Symbol	Process parameters	Level -1	Level 0	Level +1
q	A: Forming pressure (MPa)	55	60	65
R	B: Radius of die (mm)	9	12	15
v	C: Speed of axial press of punch (mm/s)	3	4	5

In Box-Behnken (BBD) planning, three levels are required for each design parameter, with all design points lying on the same sphere and having at least three or five points at the center. BBD is applied instead of orthogonal planning methods to reduce the number of trials and ensure prediction accuracy. Predictive mathematical models are then developed for the process parameters using RSM. Then, a suitable analysis is performed to investigate the significance of the proposed model and the selected factor. To solve the optimization problem, an advanced technique named desired function (DF) is applied to obtain optimal values. In addition to the design points, a set of random points is checked to see if there is a more suitable solution. The influence of the parameters on the objective function will help the technology design process. Therefore, the integrated approach combining BBD, RSM and DF can be considered an appropriate method to find the optimization process parameters [13].

3. RESULTS AND DISCUSSION

3.1 Analysis of regression model

In this study, ANOVA was used to determine the completeness and significance of the models. In addition, it is used to evaluate the effect of the lack of fit on the models and the significance of the individual model coefficients. There are 17 “simulation experiments” performed based on the design of the test method as shown in table 2. For each “simulation experiment”, after setting the input parameters, run the simulation. and exploit the degree of thinning of the wall thickness of the product of the 8^{th} experiment (fig. 2). From there, determine the degree of thinning of the wall thickness of each "experiment" and put it in table 2.

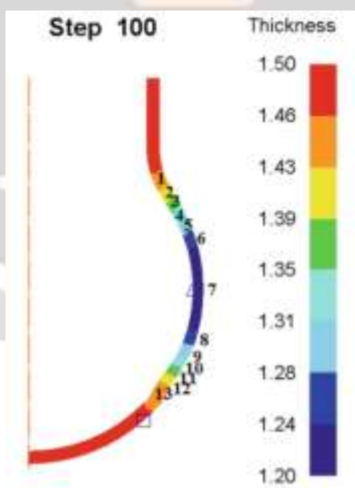


Fig - 2: Simulation results of the 8^{th} experiment

The simulation results were investigated as the distribution of the thickness of the spherical part after the SHF process. The thickness measurement locations are points along the profile of the part (fig. 2). Deviation of wall thickness from the required thickness of the product is evaluated in quantities and calculated according to the formulas:

$$S = (S_0 - S_j)/S_0 \cdot 100\% \quad (1)$$

where S_0 - workpiece thickness, S_j - part thickness at position j after SHF process.

The ANOVA results on the degree of thinning of the wall thickness of product are presented in Table 3. Significant coefficients were selected based on the p-values of the parameters considered. The parameters were modeled using the 95% confidence level. Therefore, factors with p-values less than 0,05 are considered significant. Observing Table 3, the F value is 12,42; showing that the regression models are significant. In addition, the R^2 value of the wall thickness difference is 0,941, indicating 94,1% of the total variation explained by the model. Furthermore, the comparison results from the adjusted R^2 value and the predicted R^2 value using ANOVA indicate that for the degree of wall thickness thinning, a quadratic model should be used. The full precision (Adeq. Precision) value of the model is 9,1343 greater than 4, indicating that the model guarantees reliability in the design space [14].

Table - 2: Simulation planning results

N^0	Factor 1	Factor 2	Factor 3	Results
	A: Forming pressure (MPa)	B: Radius of die (mm)	C: Speed of axial press of punch (mm/s)	R_1: The degree of thinning of the wall thickness (%)
1	-1	-1	0	18,2
2	+1	-1	0	18,6
3	-1	+1	0	16,3
4	+1	+1	0	16,8
5	-1	0	-1	17,7
6	+1	0	-1	17,5
7	-1	0	+1	17,2
8	+1	0	+1	17,8
9	0	-1	-1	18,2
10	0	+1	-1	16,8
11	0	-1	+1	18
12	0	+1	+1	16,5
13	0	0	0	16,8
14	0	0	0	16
15	0	0	0	16,4
16	0	0	0	16,8
17	0	0	0	16,6

Table - 3: ANOVA results for the degree of thinning of the wall thickness model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9,11	9	1,01	12,42	0,0016	Significant
A-A	0,2113	1	0,2113	2,59	0,1514	
B-B	5,44	1	5,44	66,81	< 0,0001	
C-C	0,0612	1	0,0612	0,7515	0,4147	
AB	0,0025	1	0,0025	0,0307	0,8659	

AC	0,1600	1	0,1600	1,96	0,2039	
BC	0,0025	1	0,0025	0,0307	0,8659	
A^2	1,34	1	1,34	16,49	0,0048	
B^2	0,6404	1	0,6404	7,86	0,0264	
C^2	0,9104	1	0,9104	11,17	0,0124	
Residual	0,5705	7	0,0815			
Lack of Fit	0,1225	3	0,0408	0,3646	0,7833	not significant
Pure Error	0,4480	4	0,1120	-	-	
Cor Total	9,68	16	-	-	-	
R^2	0,9410	-	-	-	-	
Adjusted R^2	0,8653	-	-	-	-	
Predicted R^2	0,7251	-	-	-	-	
Adeq Precision	9,1343					

3.2 Regression model

Model of the relationship between degree of thinning of the wall thickness with input parameters were built using RSM. From the simulation results, the coefficients of the regression equation are calculated. Regression coefficients of insignificant terms are removed based on ANOVA results. Regressive response surface models show the degree of thinning of the wall thickness Δs (%) expressed by Equations (1).

$$\Delta s = 16{,}52 + 0{,}1625*A - 0.852 *B - 0{,}0875*C + 0{,}025*A*B + 0{,}2 *A*C - 0{,}025*B*C + 0{,}565*A^2 + 0{,}39 *B^2 + 0{,}465*C^2 \quad (1)$$

Figure 3 shows the usual probability curve to check the completeness of the models. Since all the points are located near the line of the regression equation, it can be concluded that the built models are suitable.

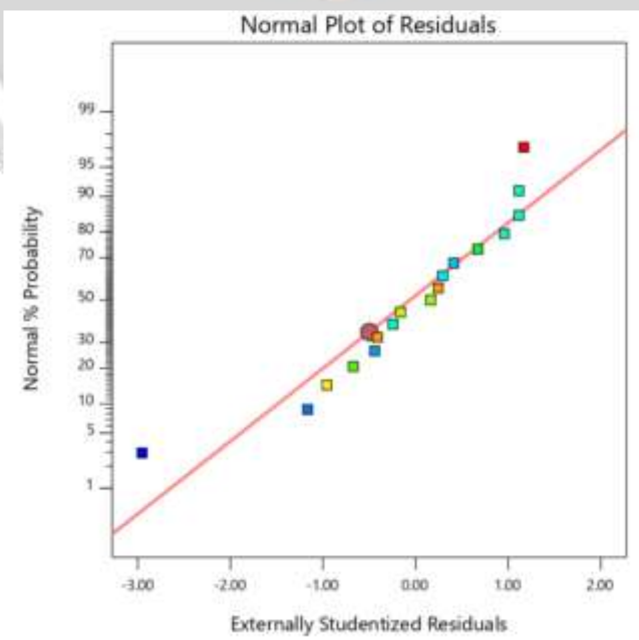
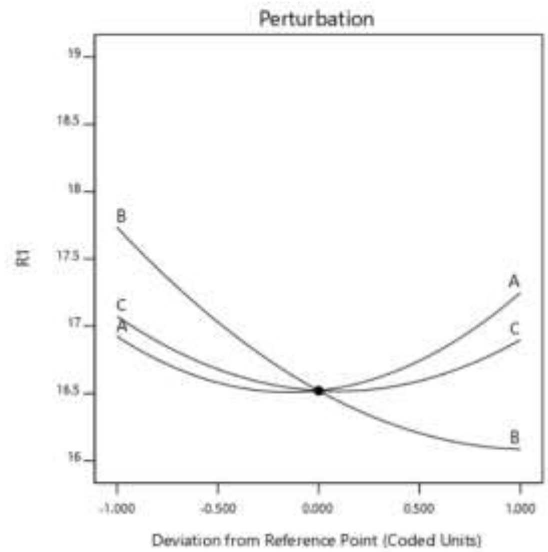
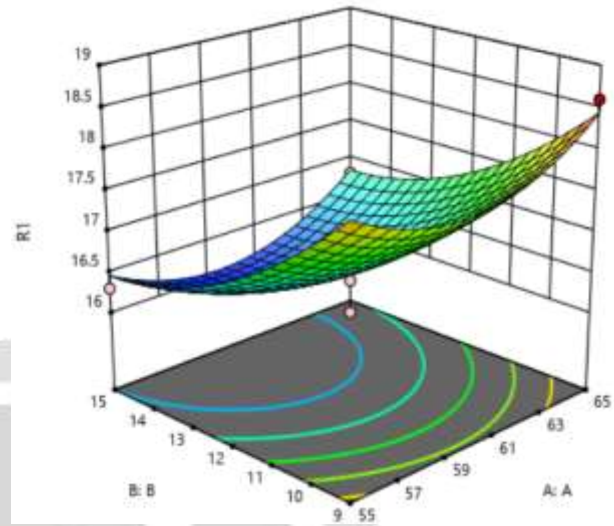


Fig - 3: Normal probability graph of models

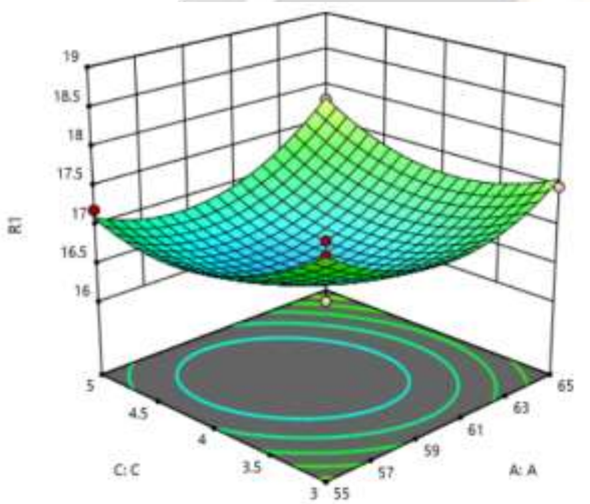
3.3 Analyze the influence of process parameters on the regression function



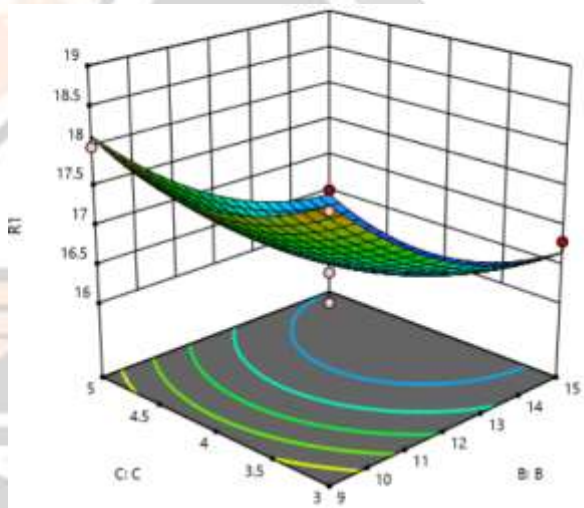
a)



b)



c)



d)

Fig - 4: Influence of process parameters on the degree of thinning of the wall thickness

The influence of process parameters on the degree of thinning of the wall thickness is shown in figure 4. When the forming pressure system and the axial movement speed of the punch are increased, the difference in wall thickness decreases. However, when the coefficients increase to a certain value, the degree of thinning of the wall thickness increases. The radius of the die also affects the degree of thinning of the wall thickness, as the radius of the die increases, the degree of thinning of the wall thickness is reduced.

The reason is that in the first stage, the forming pressure and the speed of axial press of punch increase to a suitable value, which helps the workpiece to avoid instability and still smoothly pull the workpiece into the cavity of the die. The workpiece is easily pressed against the wall of the die, so the degree of thinning of the wall thickness is reduced. In the next stage, the forming pressure and the speed of axial press of punch after reaching the optimal value continue to increase, the workpiece is pressed close to the profile of the die cavity. At that time, it interferes with the drawing of the workpiece into the cavity of the die, so the degree of thinning of the wall thickness increases.

3.4 Determining the optimal set of process parameters

After building a regression model showing the relationship between process parameters to the objective function value, use these regression functions to optimize process parameters. According to the above analysis results, it can be concluded that process parameters such as coefficient of friction, taper angle and spool factor have a significant and complex influence on the degree of thinning of the wall thickness. The RSM method was used to determine the optimal set of parameters and the smallest degree of thinning the wall thickness of the product in this work.

Using Design Expert 12 software, the smallest degree of thinning the wall thickness is 16%, corresponding to the forming pressure q = 59 MPa, the radius of die R = 15 mm and the speed of axial press of punch v = 4,17 mm/s.

4. CONCLUSIONS

The main conclusions that can be drawn from the study are:

1) The paper has conducted research on the SHF process for the parts of space. Evaluate the influence of process parameters such as forming pressure (q), radius of die (R) and speed of axial press of punch (v) on the degree of thinning of the wall thickness by using Deform 2D deformation simulation software.

2) The paper has performed simulation planning by RSM response surface method, and ANOVA analysis. The results show that the process parameters such as forming pressure, radius of die and speed of axial press of punch affect the degree of thinning of the wall thickness. A regression function model is defined, where the model for the degree of thinning of the wall thickness is a quadratic model.

3) The minimum degree of thinning of the wall thickness is 16,238%, corresponding to the forming pressure q = 59 MPa, the radius of die R = 15 mm and the speed of axial press of punch v = 4,17 mm/s.

4) Experimental studies on the mutual influence of process parameters on the deformation ability of materials in the SHF process for the parts of space will continue to be studied.

5. REFERENCES

[1]. Kocanda, A., Sadłowska, H.: Automotive component development bymeans of hydroforming. Arch. Civil Mech. Eng. 8(3), 55–72 (2008).
[2]. Vollertsen, F., Prange, T., Sander, M.: Hydroforming: needs, developments and perspectives. In: Proceedings of the Sixth International Conference on Technology Plasticity, Advanced Technology of Plasticity, Berlin, Germany, vol. 6, pp. 1197-1210 (1999).
[3]. Zhang, S., Wang, Z., Xu, Y., Wang, Z., Zhou, L.: Recent developments in sheet hydroforming technology. J. Mater. Process. Technol. 151, 237–241 (2004).
[4]. Vahl, M., Hein, P., Bobbert, S.: Hydroforming of sheet metal pairs for the production of hollow bodies. In: ATS International Steelmaking Conference, Paris, Session 4 (1999).
[5]. Muam mer Koc, Hydroforming for advanced manufacturing, Woodhead publishing limited, Cambridge England, 2008.
[6]. S.H. Zhang, Developments in hydroforming, Journal of Materials Processing Technology, 91, 236-244 (1999).
[7]. Abdelkhalik Eladl, Ossama B. Abouelatta, Magdy Samuel, Tawakol A. Enab, Effect of Hydroforming Drawing Cups on Thickness Variation and Surface Roughness, International Journal of Engineering Research in Africa, 59, 1–18 (2022).
[8]. Harjinder Singh, Fundamentals of hydroforming, Society of Manufacturing Engineers, 2003.
[9]. C. Hartl, Research and advances in fundamentals and industrial applications of hydroforming, Journal of Materials Processing Technology, 167, 383-392 (2005).
[10]. Gather, U., Homberg, W., Kleiner, M., Klimmek, Ch., Kuhnt, S.: Parameter design for sheet metal hydroforming processes. University of Dortmund, Germany.
[11]. G. Palumbo, S. Pinto, L. Tricarico, Numerical/experimental analysis of the sheet hydro forming process using cylindrical, square and compound shaped cavities, Journal of Materials Processing Technology vol 155 -156, Pages 1435–1442 (2004).

[12]. Kleiner, M., Homberg, W.: New 100,000kN Press for Sheet Metal Hydroforming. In: Siegert, K. (ed.) Hydroforming of Tubes, Extrusions and Sheet Metals, vol. 2, pp. 351–362 (2001).

[13]. Manh Tien Nguyen, Truong An Nguyen, Duc Hoan Tran, Van Thao Le, Advances in Technology Innovation vol 6, no.4 2021: Optimization of Superplastic Forming process of AA7075 Alloy for the Best Wall Thickness Distribution, 251-261 (2021).

[14]. Myers R. H., Montgomery D. C., Anderson-Cook C. M. (2016), Response Surface Methodology Process and Product Optimization using Designed Experiments - 4th edition, Wiley series in probability and statistics, USA.