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Study on Influence of Process Parameters to Superplastic Forming from AA7075 Aluminum Alloy Sheet

Manh Tien Nguyen [1,]*, Truong An Nguyen [2], Duc Hoan Tran [3] and Tuan Linh Vu [4]

[1] Faculty of Mechanical Engineering, Le Quy Don Technical University, Hanoi 100000, Vietnam; Manhtiennguyen84@gmail.com
[2] Faculty of Mechanical Engineering, Le Quy Don Technical University, Hanoi 100000, Vietnam; truonganomd@gmail.com
[3] Faculty of Mechanical Engineering, Le Quy Don Technical University, Hanoi 100000, Vietnam; duchoan1012@gmail.com
[4] General Department of Military Industries and Manufacture, Ha Noi 100000, Viet Nam; vutuanlinhk44@gmail.com
* Correspondence: manhtiennguyen84@gmail.com
† Presented at the title, place, and date.

Abstract: The paper introduces the experimental research results of superplastic forming (SPF) of AA7075 aluminum alloy sheet. The response surface methodology (RSM) based on a Box-Behnken design (BBD) were used to study the influence of process parameters on the superplastic forming ability. The analysis show the relationship between the relative height of the product and the main process parameters: forming pressure of 0.7-0.9 MPa, deformation temperature of 500-530^{0}C and forming time of 20-40 minutes. The experimental results are consistent with the general trend of the superplastic forming process: the relative height of the product increases with increasing pressure, temperature, and forming time. However, there exist limit values of forming time, where the law of the influence of temperature and forming pressure on relative height is reversed. Therefore, in each specific machining case, it is necessary to select the range of appropriate process parameters to get the desired results.

Keywords: Metal forming; SPF; RSM; process parameters; AA7075 aluminum alloy sheet

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1. Introduction

Superplasticity is the ability of a material to deform to a large degree under certain conditions of microstructure, temperature, and strain rate [1,2]. The superplastic forming (SPF) process is based on superplasticity, which enables the fabrication of complex parts from high-strength materials. However, SPF is difficult to perform on normal equipment because the required strain rate (machining speed or device speed) is very small, only from 10^{-4} to 10^{-2} s^{-1}. Therefore, SPF under gas pressure is the commonly used method for sheet metal, because the gas pressure meets the condition of strain rate for forming process. It is the characteristics of this method that the SPF ability is being widely applied in the manufacture of industrial products [3,4]. Sheet superplastic forming (SSPF) allows hollow parts to be obtained from flat or space-shaped workpieces or tube blanks by gas pressure. The obtained part has the profile of the tools [5,6]. The advantage of the SSPF is the implementation process simpler, less metal waste, reduce costs. However, the disadvantage of this method is the long forming time and low productivity.

Process factors that greatly affect the deformability of SSPF include strain rate, forming pressure, deformation temperature, forming time, tool size, coefficient friction…. The affecting of factors is evaluated through many output parameters such as product height, wall thickness distribution, surface quality, and micro-destructive ability [7,8].

Kumaresan et al. [9] studied the influence of process parameters on the wall distribution of a rectangular cup of Al 7075 Alloy. The process parameters mentioned are the forming pressure and the initial sheet thickness. These research results allow to determine the best degree of thinning of the wall corresponding to reasonable process parameters. Muthusamy Balasubramanian et al. [10] have an approach to SSPF with a combination of simulations and experiments. Simulation results using Abaqus software allow determining the influence of process parameters on the height of a three-stage hemispherical. Through the simulation results, the experimental parameters are determined. The application of numerical simulation in determining process parameters helps to reduce production time and costs.

In this study, the experimental process of SSPF under gas pressure was performed for high strength aluminum alloy AA7075. The response surface methodology (RSM) based on a Box-Behnken design (BBD) were used to study the influence of process parameters on the superplastic forming ability. The analysis show the relationship between the relative height of the product and the main process parameters: forming pressure of 0.7-0.9 MPa, deformation temperature of 500-530^{0}C and forming time of 20-40 minutes. The experimental results are consistent with the general trend of the superplastic forming process: the relative height of the product increases with increasing pressure, temperature, and forming time. However, there exist limit values of forming time, where the law of the influence of temperature and forming pressure on relative height is reversed. Therefore, in each specific machining case, it is necessary to select the range of appropriate pro-cess parameters to get the desired results.

2. Materials and methods

The research material is aluminum alloy AA7075 composition of elements by weight is analyzed and presented in Table 1. The AA7075 alloy sheet is prepared by thermomechanical process with average grain size about 13 μm to meet the SPF conditions. Tensile tests preformed in the SPF condition obtained the greatest relative elongation around 280% [12, 13]. The SSPF is used in the experimental process. The SSPF diagram is shown in Figure 1. The resulting product has the shape shown in Figure 2.

Table 1. Chemical composition of alloy AA7075 in % wt

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.032	0.05	1.32	0.024	2.34	0.222	5.35	0.042	balance

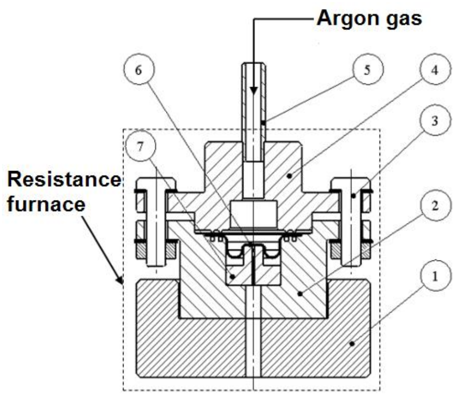


Figure 1. The SSPF diagram

The RSM based on a BBD was used to study the influence of process parameters on the SPF ability. RSM is a set of statistical and mathematical techniques established based on polynomial equations with empirical data [11, 12]. Forming pressure (X1), deformation temperature (X2) and forming time (X3) are the independent variables chosen in this experimental design, the relative height of the product is chosen as objective function (R) for combinations of independent variables. The relative height of the product is the ratio between the height of the product (H) and the maximum diameter of the product (30 mm). Table 2 shows the variation range of the influencing parameters. Table 3 lists the BBD matrix and the response values taken to develop the models. Tree experiments of each condition were performed randomly and the mean values were stated as observed responses.

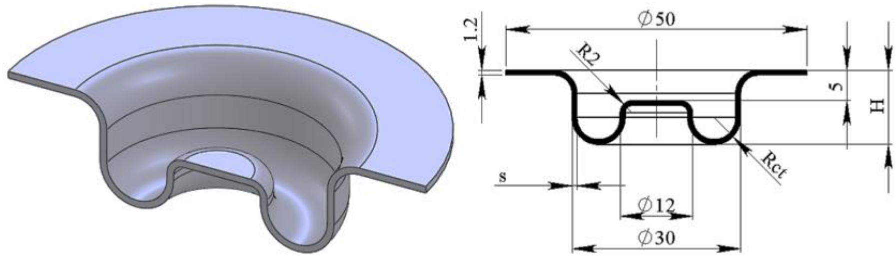


Figure 2. Cylindrical hollow detail after SSPF

Table 2. Levels and their values of the process parameters

Parameters	Level -1	Level 0	Level +1
X1: Forming pressure (MPa)	0.7	0.8	0.9
X2: deformation temperature (^{0}C)	500	515	530
X3: Forming time	20	30	40

3. Results and Discussion

ANOVA analysis was used to determine the completeness and significance of the model. In addition, to evaluate the effect of the mismatch (lack of fit) on the model and the significance of the coefficients in the model. ANOVA analysis for the relative height model terms is described in Table 4. A value of F of 25.3 indicates that the model is very significant.

Table 3. Box-Behnken experimental design and response values for relative height of product

Run	Parameter 1	Parameter 2	Parameter 3	Responses
	X1: Forming pressure (MPa)	X2: Deformation temperature (^{0}C)	X3: Forming time (min)	R: relative height of the product
1	-1	-1	0	0.25
2	+1	-1	0	0.32
3	-1	+1	0	0.30
4	+1	+1	0	0.37
5	-1	0	-1	0.34
6	+1	0	-1	0.27
7	-1	0	+1	0.40
8	+1	0	+1	0.49
9	0	-1	-1	0.30
10	0	+1	-1	0.42
11	0	-1	+1	0.33
12	0	+1	+1	0.45
13	0	0	0	0.48

14	0	0	0	0.48
15	0	0	0	0.44

In this model, the values of the coefficient of determination R^2 and the adjusted coefficient of determination (Adjusted R^2) are greater than or equal to 90%, which indicates that the models are found to be statistically significant. In the relative height model R^2 = 0.974 means 97.4% of the total variation observed in this model. In model above the Adeq Precision value measures the signal-to-noise ratio. This ratio is greater than 4 (Adeq Precision of 15.1235), showing that the signal confirms the statistical significance of the obtained model.

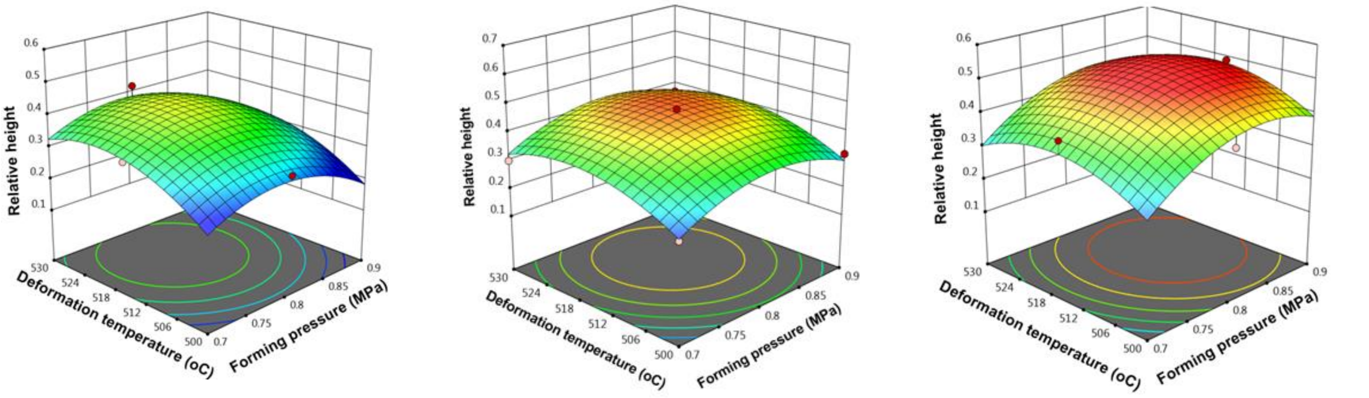
Table 4. Results of ANOVA for relative height of product of SSPF

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0836	9	0.0093	25.93	25.93	significant
X1-X1	0.0036	1	0.0036	10.08	10.08	
X2-X2	0.0136	1	0.0136	37.99	37.99	
X3-X3	0.0162	1	0.0162	45.21	45.21	
X1X2	0.0006	1	0.0006	1.74	1.74	
X1X3	0.0121	1	0.0121	33.77	33.77	
X2X3	0.0009	1	0.0009	2.51	2.51	
$X1^2$	0.0285	1	0.0285	79.64	79.64	
$X2^2$	0.0103	1	0.0103	28.85	28.85	
$X3^2$	0.0009	1	0.0009	2.45	2.45	
Residual	0.0018	5	0.0004			
Lack of Fit	0.0009	3	0.0003	0.7115	0.7115	not significant
Pure Error	0.0009	2	0.0004			
Cor Total	0.0854	14				
R^2	0.9790					
Adjusted R^2	0.9413					
Predicted R^2	0.8039					
Adeq Precision	15.1235					

3.1. Efect of forming pressure and deformation temperature on relative height of product

The influence of forming pressure and deformation temperature on the relative height of the product is presented on the response surface plots of Figure 3. When the forming time is short (Figure 3a), the relative height of the product depends on the forming pressure and the deformation temperature. With the general trend is that when the deformation temperature and forming pressure increase, the relative height of the product increases.

When the forming time is long (Figure 3c), it is found that with the values of forming pressure in range 0.7÷0.75 MPa, the relative height of the product increases with increasing temperature. However, when the forming pressure value above 0.75 MPa, when the deformation temperature increases to a certain value, the product height increases. When the deformation temperature continues to increase, the relative height of the product tends to decrease. This can be explained because when the pressure increases, the deformation rate of the workpiece increases, together with the high deformation temperature will reduce the deformation ability of the workpiece.

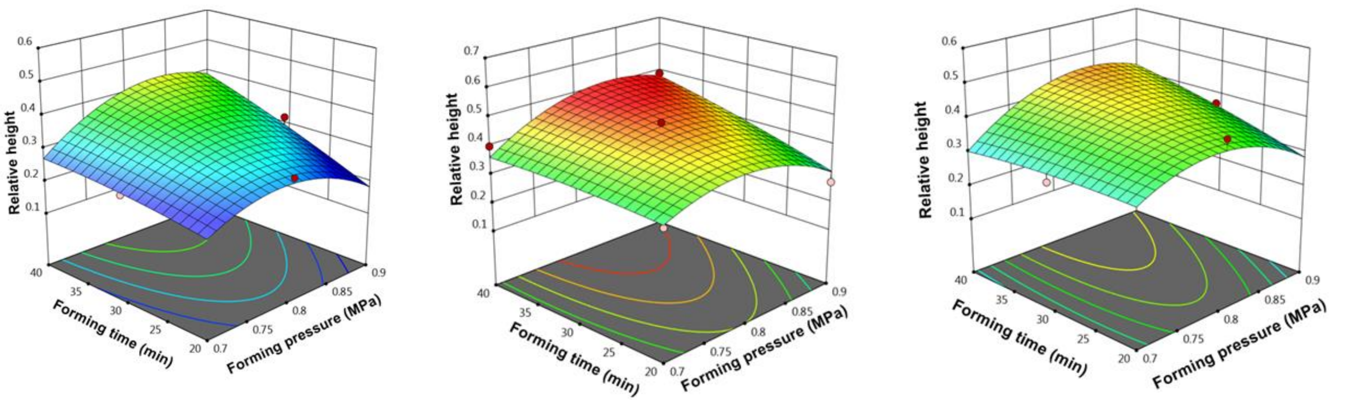


(a) (b) (c)

Figure 3. Response surface plots showing the efect of the forming pressure (X1), deformation temperature (X2) on relative height of the product: (**a**) forming time of 20 min; (**b**) forming time of 30 min; (**c**) forming time of 40 min

3.2. Efect of forming pressure and forming time on relative height of product

The influence of forming pressure and forming time on the relative height of the product is presented on the contour plots of Figure 4. With each forming pneumatic pressure, the relative height of the product increases as the forming time increases. In Figure 4b, the relative height of the product reaches its maximum value at 0.9MPa, 515^{0}C, 40 min). When forming with the same time, it was found that when the forming pressure is more than 0.8 Mpa, the forming pressure increases, the relative height of the product increases. When forming pressure below 0.8 MPa, the forming pressure increases, the relative height of the product tends to decrease.



(a) (b) (c)

Figure 4. Response surface plots showing the efect of the forming pressure (X1), forming time (X3) on relative height of the product: (**a**) deformation temperature of 500^{0}C; (**b**) 515^{0}C; (**c**) 530^{0}C

3.3. Efect of deformation temperature and forming time on relative height of product

The influence of deformation temperature and forming time on the relative height of the product is presented on the response surface plots of Figure 4. The influence of deformation temperature and forming time on the relative height of the product is shown on the response surface plots of Figure 5. When the forming pressure is increased, the relative bigger height is obtained. When deformation with a certain temperature, the relative height of the product increases as the deformation time increases. When deforming with the same time, the relative height of the product increases as the deformation temperature rises to a certain value, then the product height tends to decrease as the temperature increases. This is explained by increasing the temperature, which accelerates the growth of the grain, which leads to a decrease in the strain rate and thus the degree of deformation of the AA7075 alloy.

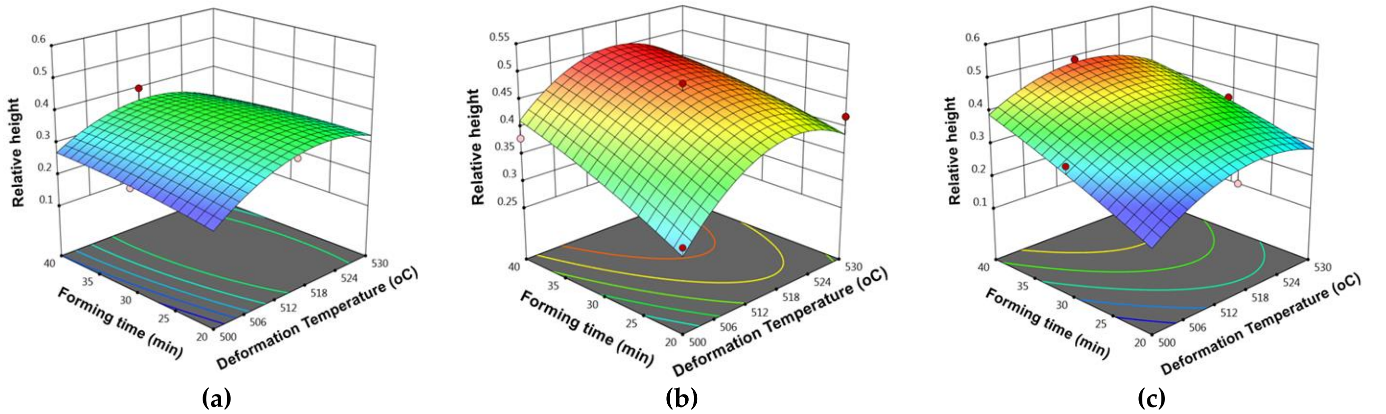


Figure 5. Response surface plots showing the efect of the deformation temperature (X2), forming time (X3) on relative height of the product: (**a**) forming pressure of 0.7 MPa; (**b**) 0.8 MPa; (**c**) 0.9 MPa

4. Conclusion

The paper studied the influence of some main process parameters: forming pressure, deformation temperature, and forming time on the relative height of product in SSPF from high-strength aluminum alloy sheet AA7075. In the survey area, including forming pressure (0.7÷0.9 MPa), deformation temperature (500÷530°C) and forming time (20÷40 minutes) found that, as the forming pressure, deformation temperature and forming time increased, the relative height of the product increased. However, when the forming pressure or deformation temperature increases to a certain value, the relative height of the product tends to decrease. The obtained research results help determine the laws of mutual influence, the influence of the process parameters on the deformation ability in SSPF with complex shapes, thereby recommending the selection of a reasonable set of process parameters in the forming process and actual production, contributing to reducing design and testing time, improving productivity and product quality.

Conflicts of Interest:

The authors declare no conflict of interest.

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