RESEARCH ON THE FORMING ANGLE OF A1050-H14 ALUMINUM MATERIAL PROCESSED BY USING SINGLE POINT INCREMENTAL FORMING TECHNOLOGY (SPIF)

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ABSTRACT: *Single Point Incremental Forming – SPIF is the recent manufacturing process of metal sheet forming by drafting a non-cutting edge sphere-tip tool on a clamped metal sheet. The formability of metal sheet in SPIF is considered by the forming angle (ψ)- the maximum draft angle so that the material is not torn. The experimental research on A1050-H14 aluminum sheet on Bridge Port VMC500-16 CNC milling machine in C1 workshop of the HCMUT in order to find out the regression equations to predict the maximum forming angle in the relation with four most important technology parameters in SPIF: size of the step down z, forming feed v_{xy}, spindle speed n, forming tool diameter d.*

Keyword: *SPIF, ISF, Single Point Incremental Forming.*

1. INTRODUCTION

The forming angle ψ is affected by many process parameters [3] [4] such as size of the step down z, forming feed v_{xy}, spindle speed n, forming tool diameter d, friction, material,…. This paper surveys four parameters z, v_{xy}, n and d on the formability of aluminum sheet A1050-H14 by single point incremental forming method. The process is performed through the following steps:

- Studying the experiments on the cone-hyperboloid model to find out the limited draft angle ψ on a series of empirical models of 24 runorders by CNC milling machine.

- Checking the angle ψ on the cone and pyramid models, the process also machines 24 runorders.

- The experiment planning method is used for processing the gathering datum to find out the effects of four parameters on the limited forming angle. The final results are two regression equations describe how the parameters affect on the formability, thence optimizing the parameters in order to gain the best forming angle in the specific industry applications.

2. DESIGN OF EXPERIMENTS

2.1. Experiment equipments

Sheet material: Aluminum A1050-H14, thickness 1mm, square 280mm.

Machine: Milling machine 3 axes Bridge Port VMC500-16, travels: 500x340x310mm, motor power 7,5KW, maximum spindle 4000rpm.

Fixture: consits of two main components: backing plate and blankholder. Backing plate creates a clear change of angle at the sheet surface. The connections between components use 12 hexagon socket screws (*figure 1*).

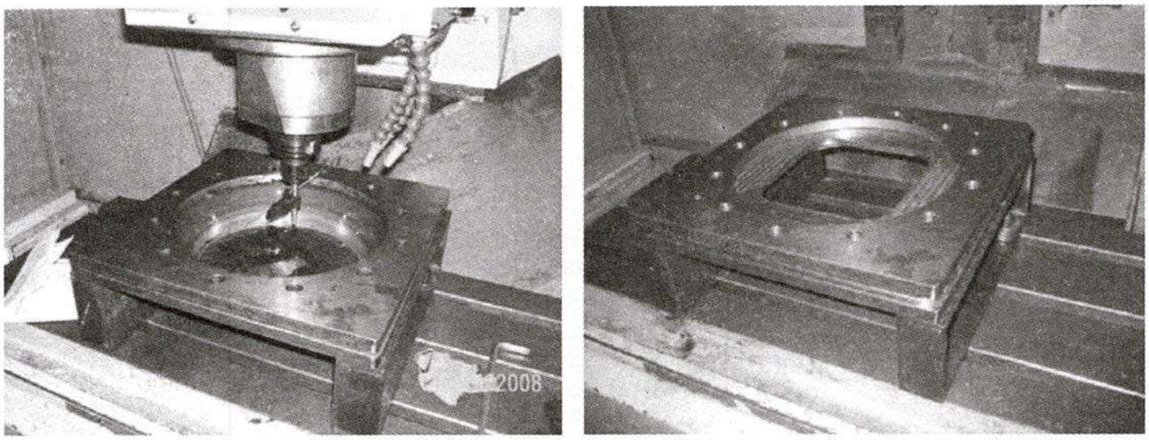


Figure 1. Cone and pyramid models fixture

Lubrication: Engine oil – grease mixture, ratio 3:1. Lubrication appears to be an important factor in sheet metal forming. It reduces friction at the tool-workpiece interface and improves surface quality.

The forming tool: High speed steel sphere-tip tool with 5mm and 10mm diameter *(fig. 2)*.

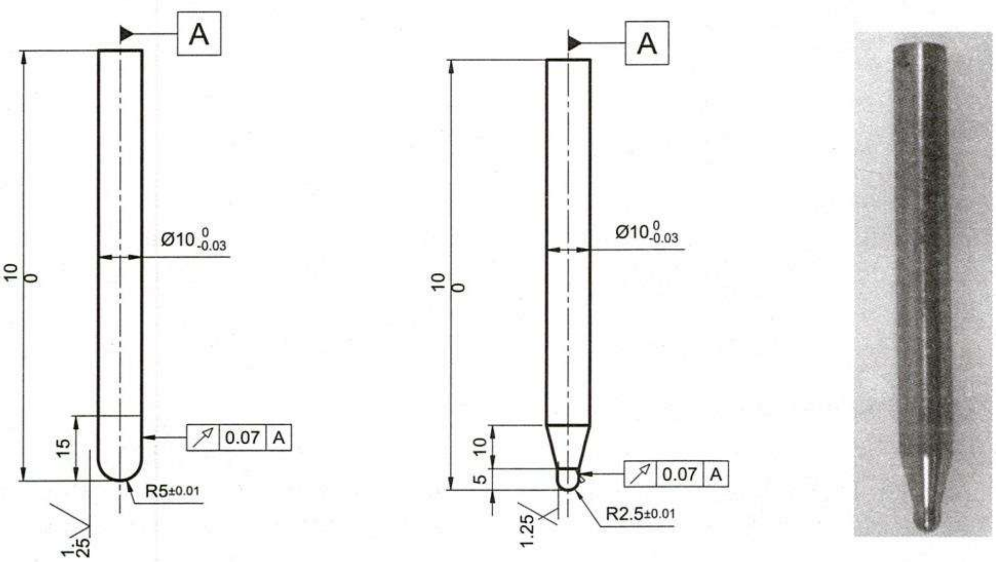
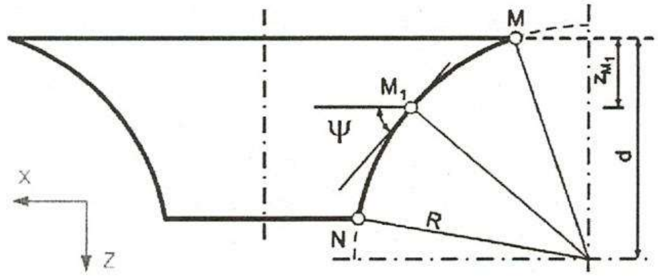


Figure 2. The forming tool

2.2. CAD/CAM empirical models

CAD models

For conventional survey and referencing the published researchs on the world, the cone-hyperboloid model is used due to its draft angle ψ increased corresponding the depth z *(figure 3)*. Because of the formability of sheet aluminum rather high, the survey angle range between 60 and 85 degrees. Moreover, because of the workspace limitation, the maximum depth z is 60mm.



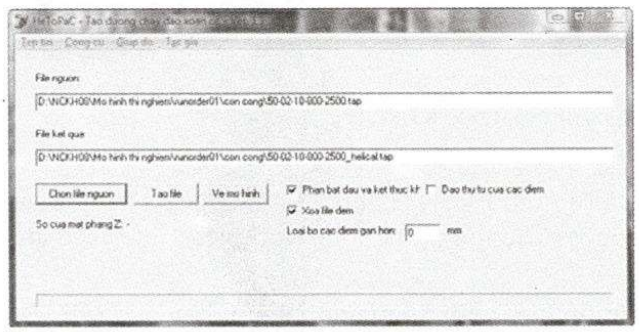


Figure 5. The "HeToPaC – Tao duong chay dao xoan oc - Ver. 1.1" program interface.

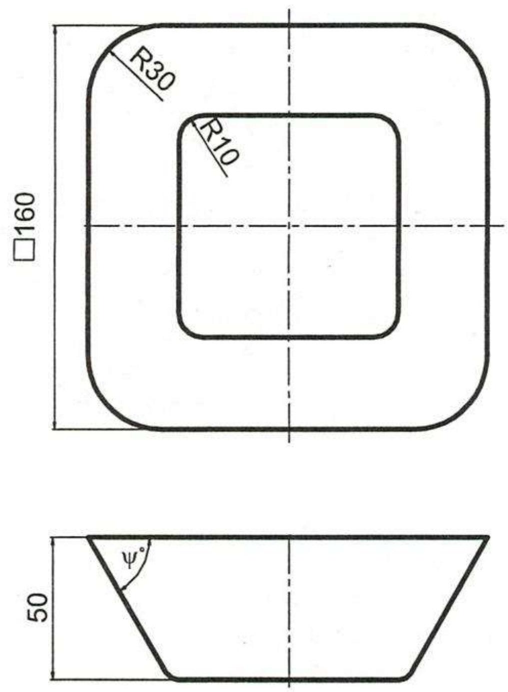


Figure 4. The pyramid model

$$\psi = \arccos\left(\frac{x}{R}\right) \text{ where } x = d - z_{M_1} \qquad (1)$$

After surveying the maximum forming angle ψ in cone-hyperboloid model, we check the maximum forming angle ψ by cone model. The cone model has a start curve segment in oder not to make a sudden change of angle, so that avoiding the unexpected formings.

The pyramid model has the draft angle ψ from the above cone model. The dimensions are given in the following figure (*figure 4*).

CAM models and toolpath strategy

This experiment study was performed using the CAD/CAM system ProEngineer Wildfire 4.0 of Parameter Technology Company (PTC). The start point is the center of the circle, the tool runs in the free-feed mode to the radius about 120mm and lowers *z* axis with step-depth *z*. The sphere-tip tool makes the sheet deform on the contour with diameter 240mm. After finishing the first contour, the tool continues to lower step-depth *z* and the process repeats until the part is finished.

In SPIF the selection of toolpath strategy is very important. Below, the "HeToPaC – Tao duong chay dao xoan oc - Ver. 1.1" program [5] (*figure 5*) is used to generate type-helical toolpath, the result which is the step-down line is eliminated and improves the formability of metal sheet.

2.3. Experiment planning data table

In oder to survey the effect of 4 technology parameters (z, v_{xy}, n, d) on the forming angle ψ, the experiment planning method was used. In details, the partial planning method with an amounts of necessary experiments is calculated as following: $N = 2^{k-1} = 8$

where k: number of survey, k = 4 (size of the step down z, forming feed v_{xy}, spindle speed n, forming tool diameter d)

Table 1. The range of the parameters

Parameters	Levels			Deviation
	Low -1	Average 0	High +1	
Size of the step down (x_1)	0.2	0.6	1	0.4
Forming feed (x_2)	800	1900	3000	1100
Spindle speed (x_3)	400	1450	2500	1050
Forming tool diameter (x_4)	5	7.5	10	2.5

Table 2. The planning matrix

Run Order	Size of the step down z (mm)	Forming tool diameter d (mm)	Forming feed v_{xy} (mm/min)	Spindle speed n (rpm)
1	0.2	10	800	2500
2	1	5	3000	400
3	1	10	800	400
4	0.2	10	3000	400
5	1	10	3000	2500
6	0.2	5	800	400
7	1	5	800	2500
8	0.2	5	3000	2500

For calculating the repeated error of the experiments, each case is performed 3 parallel experiments, m=3. So there are total 8x3=24 experiments. The experiment order is arranged randomly to increase the reliability.

2.4. Performing steps

Step 1: running cone – hyperboloid model, measuring torn position, so calculate the maximum draft angle by the above equation (1) *(figure 3)*.

Step 2: checking the maximum forming angle ψ by cone model. The start of survey angle less than 5° to cone – hyperboloid model. If the sheet is torn, decreases 1° or increases 1°.

2.5. Experiment results

2.5.1. Cone – hyperboloid model

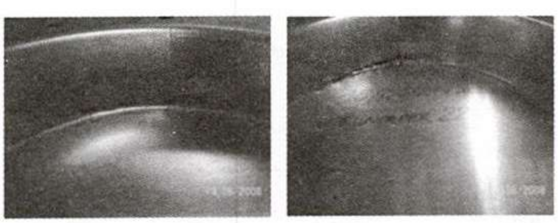


Figure 6. Cone-hyperboloid part

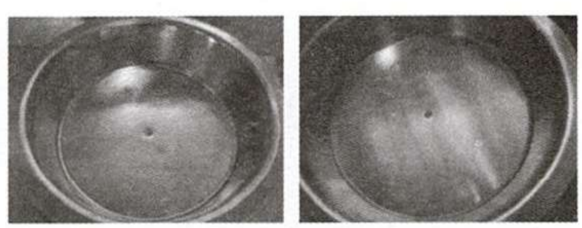


Figure 7. Cone model

Table 3. The maximum forming angle ψ_{max} in cone - hyperboloid model (degree)

Run Order	Size of step down z (mm)	Forming tool diameter d (mm)	Forming feed v_{xy} (mm/min)	Spindle speed n (rpm)	ψ_{max}	Time (min)
1	0.2	10	800	2500	85	247
2	1	5	3000	400	80.6	20
3	1	5	800	2500	82.13	50
4	0.2	5	3000	2500	83.45	65
5	0.2	5	800	400	82.55	240
6	1	10	800	400	79	60
7	0.2	10	3000	400	78.48	65
8	1	10	3000	2500	77.36	30
9	1	5	3000	400	80.18	25
10	1	5	3000	400	80.45	25
11	1	5	800	2500	84	55
12	0.2	5	800	400	82.91	240
13	0.2	5	3000	2500	82.63	60
14	1	5	800	2500	83.64	55
15	0.2	5	800	400	83.4	225
16	0.2	5	3000	2500	83.76	68
17	0.2	10	3000	400	82.18	67
18	0.2	10	3000	400	80.26	65
19	1	10	3000	2500	78.58	18
20	1	10	800	400	79.29	50
21	1	10	800	400	80.28	45
22	1	10	3000	2500	80.26	20
23	0.2	10	800	2500	82.43	255
24	0.2	10	800	2500	82.04	250

2.5.2. Cone model

The experiment consists of 8 cases, each case is repeated 3 times, so total 24 times (runorder).

Table 4. The maximum forming angle ψ_{max} in cone model (degree)

Case	Parameters				Results ψ_{max}		
	z (mm)	d (mm)	v (mm/min)	n (rpm)	y_1	y_2	y_3
1	0.2	10	800	2500	76	75.4	75
2	1	5	3000	400	75.6	76.2	75.3
3	1	10	800	400	73	73	72
4	0.2	10	3000	400	74.76	76.2	75.3
5	1	10	3000	2500	75	73.6	73.26
6	0.2	5	800	400	78.6	78.4	77.9
7	1	5	800	2500	77	78.5	78
8	0.2	5	3000	2500	76.4	76.76	77.63

2.5.3. Pyramid model

The results of 24 runorders in the pyramid model.

Table 5. The maximum forming angle ψ_{max} in pyramid model (degree)

Case	Parameters				Results ψ_{max}		
	z (mm)	d (mm)	v (mm/min)	n (rpm)	y_1	y_2	y_3
1	0.2	10	800	2500	65	67	64
2	1	5	3000	400	70	70	70
3	1	10	800	400	66	67	65
4	0.2	10	3000	400	63	64	63
5	1	10	3000	2500	70	70	70
6	0.2	5	800	400	70	70	70
7	1	5	800	2500	70	70	70
8	0.2	5	3000	2500	74	76	77

3. PROCESSING DATA AND DISCUSSION

For conventional calculation, tranferring from the natural coordinate system to the non-dimension coordinate system by assigning the average level to origin. The variables x_1, x_2, x_3, and x_4 correspond to size of the step down z, forming feed v_{xy}, spindle speed n and forming tool diameter d.

Here: $x_1 = \frac{z-0.6}{0.4}; x_2 = \frac{v-1900}{1100}; x_3 = \frac{n-1450}{1050}; x_4 = \frac{d-7.5}{2.5}$

Table 6. Planning matrix after encrypting.

No	x_1	x_2	x_3	x_4
1	-1	-1	1	1
2	1	1	-1	-1
3	1	-1	-1	1
4	-1	1	-1	1
5	1	1	1	1
6	-1	-1	-1	-1
7	1	-1	1	-1
8	-1	1	1	-1

The linear function describes the effect of 4 parameters on the maximum forming angle has the following form:

$$\psi = b_0+b_1x_1+b_2x_2+b_3x_3+b_{12}x_{12}+b_{13}x_1x_3+ b_{23}x_2x_3+b_{123}x_1x_2x_3$$

Calculating and checking the compatibility of regression equations[6]. Finally, the calculating results are following:

The regression equation of the cone model:

$$\psi = 75.7838 - 0.7463\, x_1 - 0.2838x_2 - 1.4063x_4 + 0.59125x_1x_3 - 0.32125\, x_2x_3 \text{ (degree)}$$

The regression equation of the pyramid model:

$$\psi = 68.6663 + 0.83375x_2 + 1.33375x_3 - 2.5013x_4 + 1.50125x_2x_3 \text{ (degree)}$$

Discussion:

- The forming tool diameter has a significant effect on the maximum forming angle. Decreasing tool size increases the forming angle. However, decreasing tool size makes tool less stability during the forming process.

- Step down: The size of the step down, z, (pitch) has a significant influence upon formability. When increasing z, the blank undergoes heavier deformation conditions and it decreases formability.

- Increasing spindle speed (rpm) can increase formability. The formability increase is due to both a local heating of the sheet and, what is more, a positive reduction of friction effects at the tool-sheet interface.

- Forming speed v_{xy} has a not-clearly influence. The increasing or decreasing formability depend on geometry shape and the relation with remain parameters. The above results are suitable to the published research [1][2].

Using these two regression equations, we can find out the best machine mode to help in getting the maximum deformation (table 7).

Table 7. The best machine mode for aluminum sheet A1050-H14 forming

Size of the step down z (mm)	Forming tool diameter d (mm)	Feed v_{xy} (mm/min)	Spindle n (rpm)	Predicted ψ_{max}
0.2	5	3000	2500	74,84÷76,74

Using the optimize datum to machine some models (cross and star shapes), the finish products are rather suitable and impressive *(figure 8)*.

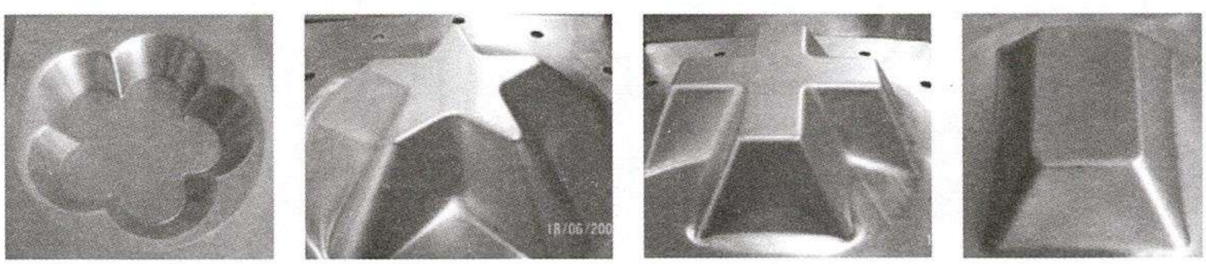


Figure 8. Complete products

4. CONCLUSIONS

The research about influences of 4 technology parameters (step down, forming feed, spindle speed, forming tool diameter) to the formability of aluminum sheet A1050-H14 thickness 1 mm showed the best machine mode to help to get the maximum deformation, so the real industry applications can be enable in order to gain the best formability.

NGHIÊN CỨU GÓC BIẾN DẠNG CỦA VẬT LIỆU NHÔM A1050-H14 ĐƯỢC GIA CÔNG BẰNG CÔNG NGHỆ TẠO HÌNH GIA TĂNG ĐƠN ĐIỂM (SPIF)

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TÓM TẮT: *Tạo hình gia tăng đơn điểm- SPIF là quá trình gia công kim loại tấm gần đây bằng cách miết một dụng cụ không lưỡi cắt đầu bán cầu trên một tấm kim loại được kẹp chặt. Khả năng tạo hình của tấm kim loại trong SPIF được đánh giá qua góc biến dạng (ψ)– là góc kéo lớn nhất tại đó vật liệu không bị rách. Nghiên cứu thực nghiệm trên nhôm tấm A1050-H14 trên máy phay CNC Bridge Port VMC500-16 tại xưởng C1 trường Đại học Bách Khoa Tp.HCM để tìm ra những phương trình hồi qui dự đoán được góc biến dạng cực đại trong mối quan hệ với 4 thông số công nghệ quan trọng nhất trong SPIF là bước xuống dọc z, tốc độ tạo hình* v_{xy}, *tốc độ trục chính n, đường kính dụng cụ tạo hình d*

Từ khóa: *tạo hình gia tăng, tạo hình đơn điểm.*

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