EXPERIMENTAL STUDY OF THE FORMING POSSIBILITY OF ISF PROCESS FOR PVC PLASTIC SHEET

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***ABSTRACTS**: This article presents an experimental study examining the effects of technological parameters to the ISF process on PVC material such as : tool diameter d, tool step depth Δz, feed rate f and forming temperature T, thereby the determining the limiting value of angular distortion α_{max}.*

***Keyword:** Experimental study, ISF process, forming possibility of PVC sheets.*

1. INTRODUCTION

Polymer materials hold a significant proportion of civil and industrial products. The traditional technique to produce polymer products based largely on the heating process - shaping - cooling, are conducted at yield or flow status to mould and is only suitable for mass production because of high energy and equipment cost. Thus, to meet the requirements for reducing cycle time and suitable to produce single pieces, small batch, rapid prototyping, we need to have innovative technologies to make new manufacturing technique flexible.

Incremental Sheet Forming (ISF) a new sheet forming process has been developed in recent years. Two types of this technology is Single point incremental forming (SPIF) and Two point incremental forming (TPIF). At first the process was studied on metal materials, later the scope was expanded on the polymer, composite. The ISF technogogy equipment is often a simple frame for clamping sheet material, while the forming is done using a device moving along the contour that is programmed by the CNC machine or industrial robot (Figure 1).

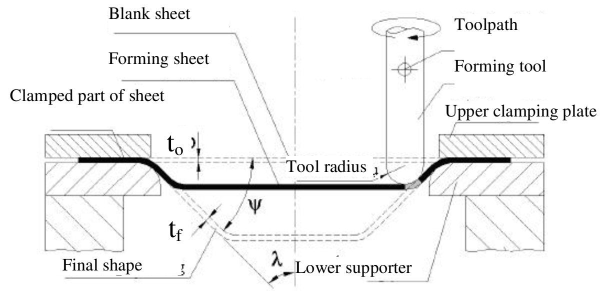


Fig.1. SPIF process [4] In the ISF process on thermoplastic sheet or PVC sheet in particular, there are many parameters affecting the forming ability of the ISF: tool diameter d, tool step depth Δz, feed rate f and forming temperature T, thereby determining the limiting value of angular distortion αmax.

2. EXPERIMENT MODEL

2.1. Cad model

According to a study has published [5], a curved cone part with curved generatrix was selected to test the forming ability. Geometry of the part is designed to study all the angles from 0 to 90^0. When the thickness of the part changes following the cosine rule and the slope of part increases with depth, the analysis area is limited to an angle smaller than 90^0 - *Figure 2.*

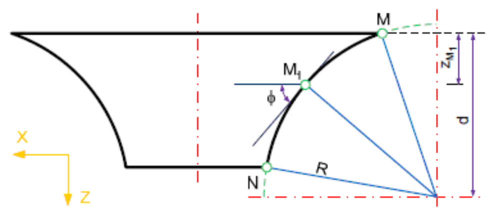


Fig.2. Curved cone contour [5]

Figure 2 shows generatrix of the part is examined through experiments. Analyzed areas to be are drawn outside arc MN. Wall angular Φ of the point on the generatrix determined by the tangent of the contour, could be calculated with formula:

$$\Phi = \arccos(x/R)$$

R is the radius of the arc and x is the coordinate perpendicular is given by:

$$x = d - z_{M1}.$$

The value of d is the maximum height of the cone and z_{M1} is the position of the tool when damage occurs. This value is recorded by the interaction of the CNC machine control device and be re-examined by the use of coordinate measuring machines (CMM).

Changing range of α from the initial deformation angle α_0 increases continuously to the largest deformation angle α_{max}. α_{max} is the received value when the wrinkle area, crushing force, or the crack appears, Figure 3.

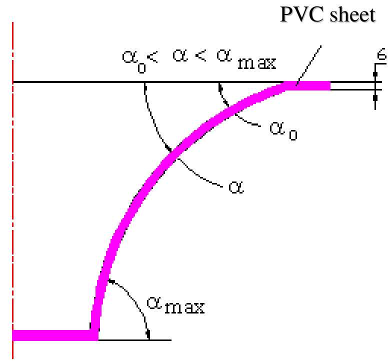


Fig.3. The increasing of deformation angle **α** with depth in ISF process [6]

2.2. Changing Parameter

Influence of parameters needs to examine are the step-down tool Δz *(mm)*, feed rate f *(mm per minute)*, forming temperature T *(^0C)*, tool diameter d *(mm)*.

Tool step depth Δz (mm):

Δz impacts significantly on the forming ability. Large down step Δz leads to large deformation force that causes difficulty for the forming ability. If tool step depth is small, forming force get smaller but can still deform workpiece plate. However, Δz should not be too small (lower than 0.3 mm – for 2 mm PVC sheet) because the part will soon be torn due by sheet thickness after shaping is pretty thin when tool stretch workpiece sheet.

Combine these factors with the capacity allowed on the CNC machine, the value of Δz was chosen from 0.4 - 1.2 mm.

Tool diameter d (mm)

Tools diameter d is related to the forming force because of stress and tearing. When the tool diameter increases, the process is the same as the traditional press, thus reducing the forming limit. However, when using the tool with the small radius, it will easily penetrate into the sheet and cause peeling. So the ability of forming is significantly reduced if the radius of the forming tools is too small.

Fig.4. *The tools has a diameter d = 6, 12 mm used in the experiments*

In addition, the diameter of tools is also driven by engine capacity. Along with the quantity Δz, f, it must meet the requirements that machine work smoothly, no vibration in the process of forming. The value d = 6 to 12 mm was chosen in this study, Figure 4.

Tool feed rate f (mm per minute)

This parameter mainly affects the productivity. Similar to tool step down Δz, depending on the value of f large or small the productivity will be high or low respectively.

In the ISF process forming the thermoplastic material, the wear caused by friction of the tools with PVC material is negligible because of the flexibility of plastic. This is an outstanding advantage of technology to reduce costs when compared with application on metallic materials. To ensure the operation does not exceed the capacity of the machine, as well as the productivity of processing the applied value f in experimental studies in the range 1000 - 2500 mm / min.

Forming Temperature T (^{0}C)

Temperature changes the mechanical properties of PVC materials (softened or hardened), it impacted significantly on the deformation of the PVC. Low temperature makes the forming ability low. Conversely, when the temperature increases the deformation capacity is higher but at the same time also receiving greater springback. To determine the optimal temperature range for the ability of the workpiece plate deformation to be the greatest, the need of performing experiments at several different temperatures. The result is the largest deformation capacity obtained at 50^{0}C temperature. Around this temperature (30-50^{0}C) is considered appropriate to conduct experimental, Figure 5.

Fig.5. *Set temperature and actual temperature at* 30^{0}C *and* 50^{0}C

a) Spindle speed n (= 900 round per min)

Spindle speed reduces sliding friction at the contact surface between the plates and tools, thus reducing tools wear and reducing the forming force. The rotational speed n is related to the temperature set value, if the difference of the temperature is large, the ability of forming significantly reduces.

b) Lubrication Cooling Solution

Lubricating the contact area between tools and workpiece surface sheet, and also works keeps the temperature stable at the molding process. However, friction remains substantially between the tools and plastic sheet. Without lubrication, temperature of the plate surface is very hot and peeling of the burrs, details will be damaged, which means deformation ability gets lower. Lubricants are used as grease, oil SAE 40 or SAE 60, with coolant emulsion to keep constant temperature during forming shows in Figure 6.

Fig.6. Mixed lubrication grease - oil SAE 40

c) Sheet thickness (= 2mm)

PVC sheet used in the experiments has the thickness of 2mm. The selection of this value related to the properties of plastic sheet and the limited capacity of the machine.

3. DEFORMATION ABILITY α

3.1 Experiment

In the process of conducting experiments, the PVC sheet with uniform thickness of 2 mm was used.

The experiments survey was conducted on a dedicated CNC machine include: 1/ a clamp holding the support plate behind the upper clamp, 2/ single point forming tool, 3/ heating fixture, (Figure 7). PVC plates are fixed by clamping plates and shaped by forming tools. The path of the tool is built by CAM model using Pro / E software.

Fig.7. ISF process on PVC sheet

3.2 Two experiment steps

Detail sample to examine in the experiments has Ø200mm diameter, depth h of 60mm. The process of running samples was carried out in 02 steps:

- First is the curved cone model, (Fig. 8). The forming is performed until the appearance of torsion or the tears. Measure the distance z at the position tearing position, we could determine the maximum angle of pull by the formula: $\cos\alpha = \dfrac{z}{R}$, Figure 9.

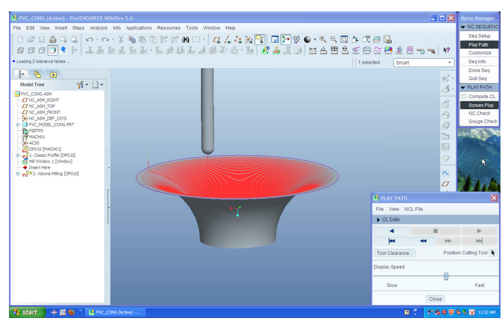


Fig.8. *Curved cone model simulated on Pro / E* with h=60mm, Ø=200mm

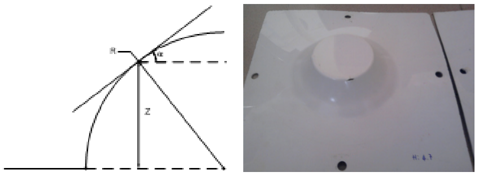


Fig.9. Model to calculate deformation angle

In some cases, when forming ability of plastic sheet is optimal, the details models after shaping is not twisted, or torn when h=60mm, (Fig. 10).

Fig.10. Details undamaged after reaching forming depth h = 60mm

Verifying the maximum angle of deformation straight cone models, (Figure11). Based on α_{max} values measured in the curved cone model that we test on straight cone model. Usually it has to reduce max value α until there is no twisting tearing, Figure 12b. Sometimes it could decrease from 3 to 5 degrees. If it is not torn then continue to increase 1 degree until tearing. Value of drag angle at the position twist or local corner tear start to appear called the largest deformation of the workpiece plate.

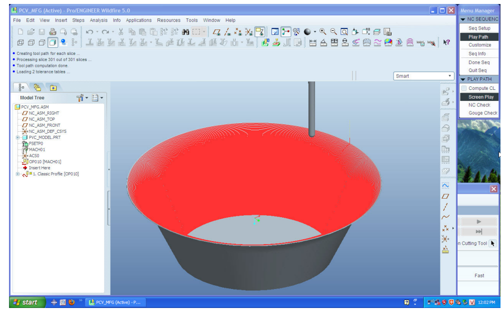
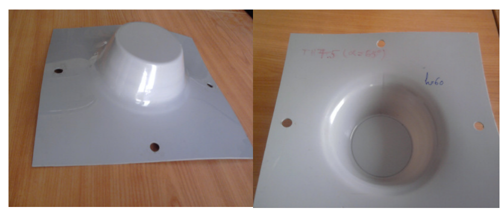


Fig.11. Straight cone model simulation on Pro / E for h = 60mm, Ø = 200mm

a)



b)

Fig.12. Straight cone model is twisted, teared (a) and undamaged after reducing of drag angle (b)

4. RESULT AND DISCUSSION

Experiment separate factors used for the survey in this study. There are 08 experiments conducted on the cone curved model. Experiments result are given in Table 1.

Table 1. Experimental Results

Order	Parameter				Result
	Step depth Δz (mm)	**Tool diameter d (mm)**	**Tool feed rate f (mm per min)**	**Forming temperature T (^0C)**	**Deformation angle α_{max}(^{0})**
1	0.4	6	1000	30	69
2	1.2	6	1000	50	66
3	0.4	12	1000	50	84
4	1.2	12	1000	30	82
5	0.4	6	2500	50	80
6	1.2	6	2500	30	76
7	0.4	12	2500	30	69
8	1.2	12	2500	50	76

The values of of drag angle deformation in the curved cone model are quite high, which is clearly shown in the table of results and images obtained after experiments, Figure 13.

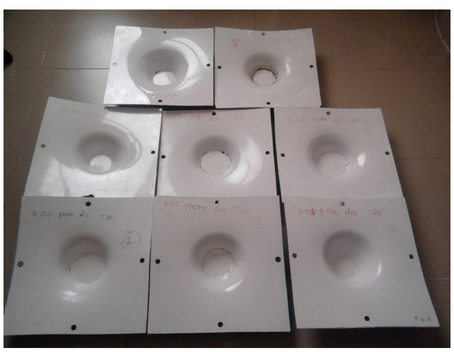


Fig.13. Some of the details after forming the curved cone model

After obtaining the value of drag angle from the experiments of curved cone model, a straight cone model is formed with this angle. In case of damage occur on the model, the higher angle will be used until the model is done. Otherwise, a decreasing angle will be applied to the model until the sheet material fall. In this case, the previous angle is obtained as maxium forming angle α_{max}.

Repeat the experiment 03 times for the selected angle for each case. This will conduct a total of 24 experiments, Figure 14. The order of 24 experiments on eight samples was randomly assigned to increase the reliability of the experiment. Results of experimental model for the straight cone are on Table 2.

Table 2. Processing result of 8 experiment with 3 duplicated times

N^0	**Input**				**Result α_{max}**		
	Δz (mm)	**d** (mm)	**f** (mm per min)	**T** ^{0}C	**y_1**	**y_2**	**y_3**
1	0.4	6	1000	30	50		
2	0.4	6	1000	30		53	
3	0.4	6	1000	30			53
4	1.2	6	1000	50	65		
5	1.2	6	1000	50		63	
6	1.2	6	1000	50			63
7	0.4	12	1000	50	65		
8	0.4	12	1000	50		65	
9	0.4	12	1000	50			66
10	1.2	12	1000	30	60		
11	1.2	12	1000	30		63	
12	1.2	12	1000	30			60
13	0.4	6	2500	50	65		
14	0.4	6	2500	50		65	
15	0.4	6	2500	50			65
16	1.2	6	2500	30	65		
17	1.2	6	2500	30		62	
18	1.2	6	2500	30			62
19	0.4	12	2500	30	55		
20	0.4	12	2500	30		57	
21	0.4	12	2500	30			57
22	1.2	12	2500	50	65		
23	1.2	12	2500	50		68	
24	1.2	12	2500	50			66

The process of repeated experiments for each case shows that the value of the angle does not change so much. However, in each different run mode, their values also have significant differences.

Fig.14. The details in the different run setting in the straight cone model

Our experimental results show that the forming ability increase with the one of the feed rate f and forming temperature T (when T=50^{o}C, f=2500mm per min, experimental result $\alpha_{max}=65^0$). The biggest impact is T, f has smaller impact.

Forming ability also increases with increasing tool step down Δz and tool diameter d (when d = 12, Δz = 1.2 value of the deformation angle in the experiments $\alpha_{max}=63^0$). The largest impact is *Δz* and *d* has no significant effect.

5. CONCLUSION

With the work already done, the paper has solved the following problems:

Experiments show the influence of the parameters Δz, d, f, and T to the deformation capacity of the PVC sheet. Successful experiments conduct on curved cone model and straight cone, determined angle α that the plastic deformation can reach 65^0.

The experiments values of the project can be used to select the mode of machining of PVC sheet by ISF suitable for the purpose of forming. Determine the limited forming angle of ISF technology could be applied in machining of PVC sheet.

NGHIÊN CỨU THỰC NGHIỆM KHẢ NĂNG TẠO HÌNH TRONG QUI TRÌNH ISF TRÊN TẤM NHỰA PVC

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TÓM TẮT*: Bài báo trình bày một nghiên cứu thực nghiệm xem xét ảnh hưởng của các thông số công nghệ trong qui trình ISF trên vật liệu nhựa PVC như đường kính dụng cụ d, bước xuống dụng cụ Δz, tốc độ chạy dao f, và nhiệt độ tạo hình T đến khả năng tạo hình α của phôi tấm, từ đó xác định giá trị giới hạn của góc biến dạng* α_{max} *trong tạo hình ISF trên tấm nhựa PVC.*

Từ khóa: *Nghiên cứu thực nghiệm, Quy trình ISF, Khả năng tạo hình tấm PVC.*

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