

# Research On The Effect Of Heating On The Formability Of Titanium By Incremental Sheet Forming Technology

NGUYEN Tan Hung, LE Khanh Dien, NGUYEN Ngoc Phuong, NGUYEN Thanh Nam

**Abstract** In the recent years, the application of Incremental Sheet Forming (ISF) in manufacturing small batch sheet products has increased rapidly, especially in medical treatment domain such as forming artificial titanium piece of human cranium because of the typical and unique cranium of each individual. This paper focus on the effect of heating on the formability of Titanium sheet material by ISF technology. Heating is one of the measures of increasing the formability of Titanium, the typical material that is permitted to manufacture the replaceable cranium. The design of experiment, the analyses of variance and the process are applied to the result of empirical process of circular lateral profile models in order to perform a regression equation that shows the relation of heat and other factors to the formability of Titanium sheet. The comparison

of the result of models manufactured in ambient temperature and in heating is also mentioned to show the effect of heating sheet in ISF technology.

**Keywords:** ISF, heating, formability metal sheet, design of experiment, analyses of variance, regression equation, mechanical engineering.

## 1 Introduction

SPIF (Single Point Incremental Forming) and TPIF (Two Point Incremental Forming) are 2 methods of ISF technology (Incremental Sheet Forming), a new dieless forming sheet technology that was recommended by E. Leszak in 1967 [1]. Figure 1 [2] shows the differences between SPIF and TPIF. From 1997 to now on, this forming sheet technology has been developed and has definitively great results in industry [3]. However; this forming sheet technology could not be applied in industry in the early years because of the weakness of the control technology of this time. In the beginning of the current century, this method has been developed rapidly and has definitive great results in industry in advanced countries... Unfortunately elasto-plastic and the limited plasticity is an inborn property of almost all materials that restrict the formability of the sheet material and caused lots of waste sheet product reduces the accuracy of the dimensions and of the shapes of the products. This paper concentrates to the effect of heating on the formability of sheet material especially Titanium because this material has had a lot of application in aeronautics and medicine especially in orthopedics. According to [4], we know that Titanium is a precious metal, in this paper we use pure Titanium grade 3 in our experiments

---

NGUYEN Tan Hung  
CAO THANG Technical college  
Vietnam

LE Khanh Dien  
The Hochiminh City University of Technology, HCMUT,  
Vietnam

LE Khanh Tan  
Hochiminh City University of Technology Education, HCMUTE  
Vietnam

NGUYENNgoc Phuong  
Hochiminh City University of Technology Education, HCMUTE  
Vietnam

NGUYEN Thanh Nam  
Digital Control and System Engineering Laboratory, DCSElab,  
Vietnam

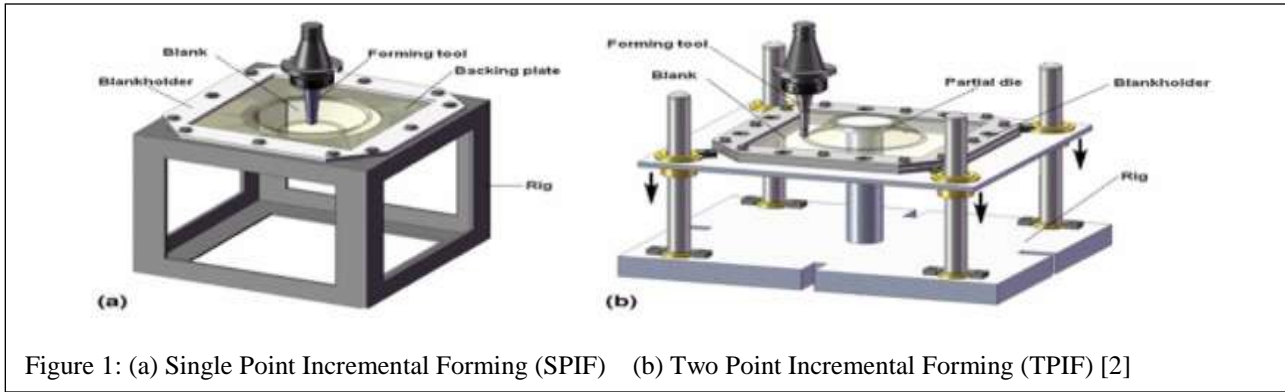


Figure 2: Good properties of Titanium

## II. Design of Experiment on the Effect of Heating on the Formability of Pure Titanium Sheet Grade 3

### A. Experimental model

In almost all SPIF experiment, the circular cone model (in figure 3) is selected because it could allow defining the deformation angle  $\alpha$  at the depth  $z$  by the

$$\text{formula } \alpha = \arccos\left(\frac{x}{R}\right) \quad (1)$$

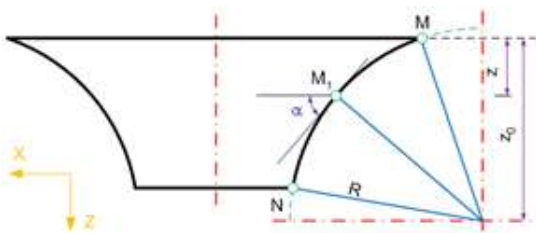


Figure 3: Model of Pure Titanium grade 3 in SPIF experiment.

### B. Experimental SPIF machine

All the experiments are performed under the support of National key Laboratory of Digital Control and System Engineering laboratory (DCSELAB), Hochiminh City. Figure 4 displays the SPIF machine in CAD-CAM workshop of DCSELAB



Figure 4: SPIF machine and feature in forming Titanium sheet, selected sheet thickness is 1mm

### C. Parameters in Design of Experiment (DOE)

In order to study the effect of heating on the formability (angle  $\alpha$ ) of pure Titanium grade 3 sheet, we select One-Haft Fraction of the  $2^k$  Design [5] in

which k=4: 4selected independent SPIF parameters: D (mm): Diameter of spherical tool tip, Δz (mm): Vertical feed after each perimeter orbit, Vxy (mm/min) : Horizontal circumference of tool velocity T(°C): Temperature of pure Titanium sheet in SPIF forming. The temperature T is selected for the replacement of the mutual effect of 3 first parameters (D, Δz, Vxy) in One-Haft Fraction of the 2<sup>k</sup> Design.

### D. Initial value of SPIF parameters by DOE

These limited values are selected due to the ability of SPIF machine, Titanium sheet, pestle tool, heating system and feature.

TABLE 1: SPIF LIMITED VALUE PARAMETER

	Input parameter value				Studied value
Rate value	D (mm)	Δz (mm)	Vxy (mm/min)	T (°C)	α (°)
Min	6	0,3	500	30	
Max	12	0,6	1500	600	

For the convenience of computing in DOE we could use encoding method. The variable x1, x2, x3, x4 are successively encoded to D, Δz, Vxy and T: Average rate  $X0=(Xmax+Xmin)/2$   
 Distance value  $\Delta X= Xmax -X0= X0 - Xmin$

TABLE 2: SPIF DOE PARAMETER VALUE

	D (mm)	Δz (mm)	Vxy (mm/min)	T (°C)
<b>Xi</b>	9	0,45	1000	315
<b>ΔXi</b>	3	0,15	500	285

Encoded parameter  $x_i=(\Delta z - X_i)/ \Delta X_i$

$x_1=(D-9)/3$

$x_2=(\Delta z -0,45)/0,15$

$x_3=(V_{xy}-1000)/500$

$x_4=(T-315)/285$

In One-Haft Fraction of the 2<sup>k</sup> Design of Experiment with k=4, the number of models is 2<sup>k-1</sup>=8. Table 3 displays the initial value of 4 independent parameters

TABLE 3: THE INITIAL VALUES OF 4 INDEPENDENT PARAMETERS

N0	Δz (mm)	Vxy (mm/ph)	D (mm)	T(°C)	α (°)
1	0,3	500	6	30	
2	0,6	500	6	30	
3	0,3	1500	6	30	
4	0,6	1500	6	30	
5	0,3	500	12	600	
6	0,6	500	12	600	
7	0,3	1500	12	600	
8	0,6	1500	12	600	

TABLE 4: ENCODING INPUT PARAMETER OF SPIF

N0	x1	x2	x3	x4=x1.x2.x3	α (°)
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 parameter x4 stands for heating temperature T is selected as the multiplication of the 3 remained parameters that represents the most robust mutual influence to the result parameter α. The selected number of replication is 3 so the total number of experiment is 8x3=24.

## III Empirical Experiment

The figures below show all the empirical experiment to research the effect of heating on the ability of forming Titanium models in Cad-Cam Workshop of DCSElab



Figure 5: Preparation of installation in SPIF machine



Figure 6: Forming Titanium model sheet by SPIF technology at 600°C with graphic powder lubrication



Figure 7: Heating system under SPIF feature 3

## VI. Treating the Empirical Experiment result by Minitab Software

The empirical experiment result of 24 runs is displays in the following table:

TABLE 5: RESULT OF EMPIRICAL EXPERIMENT OF 24 TITANIUM SHEET MODELS

N <sub>0</sub>	x1	x2	x3	x4	$\alpha_1$ (°)	$\alpha_2$ (°)	$\alpha_2$ (°)
1	-1	-1	-1	-1	69	68,58	68,78
2	1	-1	-1	1	71,98	72,26	72
3	-1	1	-1	1	71,45	71,15	71,26
4	1	1	-1	-1	67,25	67,68	67
5	-1	-1	1	1	71,32	71,56	71,12
6	1	-1	1	-1	68,28	68,14	68,45
7	-1	1	1	-1	69,15	68,92	69,25
8	1	1	1	1	71,22	71,12	71,06

In order to treat the result of DOE we could calculate or apply a design of experiment software. Herein we use Minitab [6], popular software in DOE with the successive sessions that are displayed in the following figures:

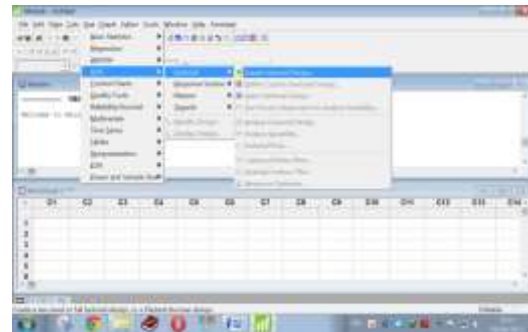


Figure 8: Minitab menu STAT/DOE/Factorial/Create factorial Design is selected



Figure 9: Create Factorial Design, 2-level, 4 factors



Figure 10 Create factorial Design with limited values  
 The Session screen displays the following result:

Estimated Coefficients for Alfa using data in encoded units

Term	Effect	Coef	SE Coef	T	P
Constant		69.12	0.2783	271.31	0.00
$\Delta_z$	1.1275	-43.32	0.2783	2.03	0.05
D	2.9442	0.243	0.2783	5.29	0.00
$V_{xy}$	1.2442	-0.0216	0.2783	2.24	0.04
T	-0.8058	0.0054	0.2783	-1.45	0.016
$\Delta_z * D$	0.8208	-0.61	0.2783	1.47	0.016
$\Delta_z * V_{xy}$	0.4125	0.0048	0.2783	-0.74	0.046

We consider that all P value are smaller or equal 0.05 so the result of DOE is reliable. The regression equation is formed by the extraction of the above coefficient values:

$$\alpha = 69,12 + 0,243D - 43,32 \Delta_z - 0,0216 V_{xy} + 0,0054T - 0,61 D \cdot \Delta_z + 0,048 \Delta_z \cdot V_{xy} \quad (2)$$

Comments:

- The formability of Titanium sheet (angle  $\alpha$ ) increases in the diameter D and heating temperature Tether formability is inverse to  $\Delta_z$  and  $V_{xy}$
- To ameliorate the formability of Titanium sheet we could increase independently the Temperature of the sheet. However the high temperature of the formed sheet could influences also to the properties of the tool and the feature and other miniature electronic instruments,

## V. Result

With Design of Experiment, the paper proposed a suitable measure of empirical experiment to determine

the good effect of heating temperature via the regression equation that determines the good influence of the heating temperature in SPIF technology.

## Acknowledgement

We appreciate highly the great support of National Key Laboratory of Digital Control and System Engineering (DCSELAB), VNU, HochiminhCity.

## References

- [1] Edward Leszak "Apparatus and Process for Incremental Dieless Forming" Patent US3342051, Ser.No. 388.577 10 Claims (Cl. 72-81)
- [2] M.B. Silva and P.A.F. Martins "Two-Point Incremental Forming with Partial Die: Theory and Experimentation", @ASM International, DOI: 10.1007/s11665-012-0400-3, JMEPEG (2013)
- [3] Mladomir Milutinovića, Robert Lendela Michal Potranb, Dragiša Vilotića, Plavka Skakuna, Miroslav Plančaka "Application of single point incremental forming for manufacturing of denture base", Journal for Technology of Plasticity, Vol. 39 (2014), Number 2
- [4] H. K. D. H. Bhadeshia "Titanium & its Alloys" Materials Science & Metallurgy Part II Course C9, Alloys.
- [5] Douglas C. Montgomery "Design and analysis of Experiments" 7<sup>th</sup> edition, John Wiley & Son ISBN 978-0-470-12866-4, 2009
- [6] Minitab 17, © 2014 by Minitab Inc.

About Author (s):



**NGUYEN Tan Hung** B.E. (2006), M.E (2009) in Mechanical Engineering from Hochiminh City University of Technology Engineering education, Head of CAD-CAM Workshop, DCSELab, HCMUT, VNU- HCM  
 Doctoral student in Single Point Incremental Forming technology since 2013



**LE Khanh Dien**, Engineer of Mechanical Engineering (1982), Master of Mechanical Engineering (1997), Lecturer of Faculty of Mechanical Engineering of HCM City University of Technology (HCMUT), Doctoral Student since 2008