International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Optimization of Surface Roughness and Improving Profile Accuracy in SPIF (Single Point Incremental Forming) Process

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Accepted 14 June 2015, Available online 18 June 2015, **Vol.5, No.3 (June 2015)**

Abstract

Single point incremental forming (SPIF) process is novel sheet metal process. In this process, a sheet blank is tightly held at the periphery and a single-point tool deforms it in incremental fashion during successive downward steps the tool moves according to a pre-defined trajectory. As a result three dimensional shaping can be obtained without die. As a critical product quality constraint, surface roughness and profile accuracy is the weak point is the incremental sheet metal forming. It is very important to identify the impact of the forming parameter on the surface roughness and the surface finish at the production stage. This paper presents a systematic approach to modeling and optimizing the effect of three various parameter's (step depth, tool diameter, and feed rate) on the surface roughness and the profile accuracy were measure over four points in conical profile. The experiments are conducted on AA 1200 H14 aluminum alloy and analyzed by the Response surface methodology wit box-behnken design. The optimum conditions for minimizing of overall roughness are determine as step dept 0.2mm, tool diameter 12mm, feed rate 1000mm/min. and for profile accuracy the percentage error is 4%.

Keywords: *Box behnken, surface roughness, profile accuracy, Incremental forming, response surface methodology.*

1. Introduction

In the last few years, the metal forming industry has seen the arrival of flexible manufacturing, the production adapting to the more and more diversified requirements of the consumers. The processes by which parts are realised through metal forming are, generally, the drawing, deep drawing, moulding or hydro forming, which allow the manufacturing of parts in large batches or as mass production. However, these processes are costly, since it is necessary to manufacture tools that follow the shape of the part that needs to be realised and for the manufacturing of a new product it is necessary to realise a new set of active tools.

More recently, new metal forming processes have appeared, such as the incremental forming processes, which eliminate this limitation. In order to realise parts using this process, it is not necessary to have costly active tools, while for realising a new product it is necessary to change only the equipment's CNC software program, for example for the incremental forming of metal sheets on milling machines, this being a very flexible forming process. At the same time, given the fact that the forming tool moves along a predefined contour, the forming time is much longer than in the case of classical forming processes. Due to this long forming time, but also due to the high flexibility degree, this forming process is suitable for the manufacturing of parts in small batches, for the manufacturing of unique parts or for rapid prototyping.

In ISF, the sheet to be formed (blank) is firmly fixed in a mobile rectangular support, independent of the final shape of the sheet. This support can perform controlled movements in the vertical direction, i.e., parallel to the Z axis of a CNC system. While the forming is taking place, fixation elements distributed around the sheet prevent it from movement, thus creating a plastic deformation in the sheet. Coupled to the spindle of a CNC device, a tool with a spherical head begins the ISF process by means of continuous movement on the surface of the plate and gradually. The great difference of the ISF is due to the fact that forming can be done with a very simplified die, or even without a die. The process appears to be very useful for small production volumes and for the speedy prototyping of sheet components.

2. Experimental Work

The experimental investigations are done on the "HURCO max" incremental forming machine. The machine is three axis CNC machines with maximum space 2100*1450*500 mm3 and can exert maximum work force of 3.0kn in Vertical axis and 1.5 KN in x and

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y axis. The maximum feed rate is 6000mm/min and min is 1000mm/min. respectively, in z axis. The forming tool with diameter 8, 10, 12 mm are used. the step dept of .2, .5 and .8 mm are used and in case of feed rate was 1000, 1500 and 2000mm/min. before started the forming experiment the blank is lubricated with the servo machine oil for better surface finish.

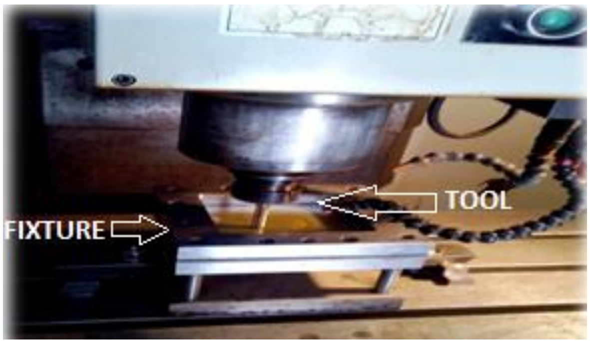

Fig.1 Hurco SPIF machine for Experiment

3. Sheet Material

AA1200 H/14 H-tempered aluminum alloy sheet with thickness 1.2 are used, which have practical and industrial wide applications Rapid prototyping for automotive industry, for example: reflexive surfaces for headlights and silencer housing for trucks.

Chemical composition of work piece

Table 1 Chemical composition

	Value		Value
Cu%	0.0063	Zn%	o.00456
Mg%	<0.00400	Pb%	<0.0200
Si%	0.393	Sn%	<0.0100
Fe%	0.552	Ti%	0.022
Ni%	0.0043	Cr%	<0.0030
Mn%	0.0239	Al%	98.92

Measuring Equipment for surface roughness and profile accuracy

The roughness of surface is measured with the mitutoyo SJ-201 roughness testing machine and the profile accuracy are studied over the CMM machine (WENZEL XORBIT XO 55).

Table 2 Independent factor and levels

S.No.	Parameter	low	Medium	High
A	Step depth	0.2	0.5	0.8
B	Tool dia.	8	10	12
C	Feed Rate	1000	1500	2000

Fig.2 Mitutoyo Roughness Tester

4. Result and Discussion

The coded three independent factors are describe in table 2.It is worth noting the main purpose of the study is to provide the modeling and analysis methodology for the surface roughness and profile accuracy. The selection of range of parameters is based on the feasibility and efficiency of actual forming and is not specially optimized.

The Design matrix generated for the box-behnken is shown in table 3.the corresponding surface roughness (μ) results are shown in the last three columns.

Table 3 Analysis of Estimated RSM Model

S.No.	Run	Step Depth	Tool dia.	Feed Rate	R_1	R_2	R_{Mean}
1	10	0.2	8	1500	0.53	0.59	0.56
2	16	0.8	8	1500	0.6	0.76	0.68
3	12	0.2	12	1500	0.39	0.45	0.42
4	3	0.8	12	1500	0.32	0.52	0.41
5	2	0.2	10	1000	0.29	0.51	0.4
6	17	0.8	10	1000	0.51	0.61	0.56
7	6	0.2	10	2000	0.45	0.76	0.61
8	4	0.8	10	2000	0.39	0.59	0.49
9	13	0.5	8	1000	0.59	0.69	0.64
10	15	0.5	12	1000	0.29	0.55	0.42
11	11	0.5	8	2000	0.47	0.69	0.58
12	5	0.5	12	2000	0.39	0.73	0.56
13	8	0.5	10	1500	0.57	0.83	0.7
14	14	0.5	10	1500	0.43	0.93	0.68
15	7	0.5	10	1500	0.51	0.85	0.68
16	1	0.5	10	1500	0.37	0.89	0.63
17	9	0.5	10	1500	0.49	0.83	0.68

To simplify the modeling process in terms of the observed experimental data, the average of the surface roughness values are taken as R_{MEAN}.

5. Estimated RSM Model

Analysis of variance (ANOVA) is adopted in order to examine the test for the importance and fitness of establishment model. The results of ANOVA for the

Table 4 Results of ANOVA for Roughness

Response 1 R1						
ANOVA for Response Surface Quadratic mode						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.174299	9	0.019367	18.3321	0.0005	significant
A-A	0.002813	1	0.002813	2.66227	0.1468	
B-B	0.052813	1	0.052813	49.9916	0.0002	
C-C	0.00605	1	0.00605	5.72684	0.048	
AB	0.004225	1	0.004225	3.99932	0.0856	
AC	0.0196	1	0.0196	18.5531	0.0035	
BC	0.01	1	0.01	9.46586	0.0179	
A^2	0.038602	1	0.038602	36.5404	0.0005	
B^2	0.015539	1	0.015539	14.7092	0.0064	
C^2	0.016844	1	0.016844	15.9447	0.0052	
Residual	0.007395	7	0.001056			
Lack of Fit	0.004675	3	0.001558	2.29167	0.22	not significant
Pure Error	0.00272	4	0.00068			
Cor Total	0.181694	16				

overall surface roughness are given in table 3. Usually p- value less than 0.5 indicate the model terms have an important impact on the response. As shown in table 3.the model f- value of 94.80 with the probability p value of less than 0.0001 implies that the model is significant. In addition it can be seen that sheet thickness is most influence factor the value of predicted r^2 is used to major the prediction ability of the established model to achieve a reasonable value of predicated r^2 and adjusted r^2 should be within approximately 0.20 otherwise problem possibility exists in the model. In this case the predicated r^2 is 0.9593 which is reasonably consists. As some of the square and the interaction term presented little effect on the model (high p value) these less significant sources can be excluded from the regression analysis, therefore the model can be simplified as:

An empirical relationship describes by a quadratic mathematical model was fitted in terms of the experimental result s derived from the box-behnken design and multi-objective function. The empirical model with the coded factors is given as follows:

R1=+0.67+0.019*A-0.081*20+0.027*C-0.032*AB-0.070*AC+0.050*BC-0.096*A2-0.061*B2-0.063*C2

6. Analysis of response surface

The three dimensional graphs are provided to illustrate the relationship between experimental factor and response .The response surface are built between the tool diameter and feed rate as showing the value of roughness is increasing with increasing the feed rate and decreasing with lowering the feed rate .

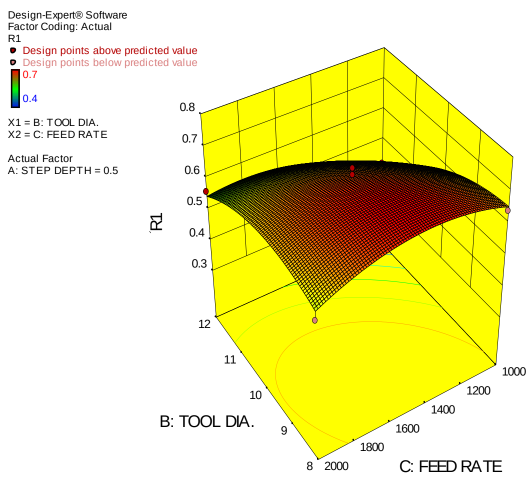

Fig.3 Tool diameter and Feed rate

The tool diameter is increasing the surface roughness is decreasing. It is proved from the ANOVA table the tool diameter is the most significant factor between all of three.

The response surface is constructed by the feed rate and tool diameter in which step depth was taken as constant 0.5. It is found that as the tool diameter is increasing, large difference can be found in terms of overall surface roughness. The roughness shows good results on the low tool diameter as shown Fig.3.

Combined effect of feed rate and tool diameter on roughness (BC)

The response surface is constructed by step depth and feed rate at 10 mm fixed tool diameter. The trend of the overall surface roughness is rise and then goes down as shown in fig.4 the roughness is high at the low feed rate and low step depth.

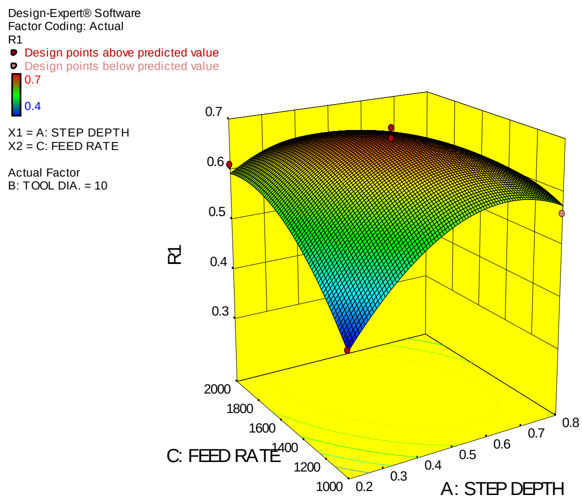

Fig.4 Step Depth and feed rate

Combined effect of feed rate and step depth on roughness (AC)

The above shown graphs discussed the optimization method for minimization of the overall surface roughness obtained from the multi–objective function with aim of simultaneous minimization for internal surface Roughness.

7. Profile accuracy

The profile accuracy is one of the important factor in the production process. For profile accuracy confirmation CMM testing are done we take four average reading on our conical profile from top to bottom and we conclude from the result that the profile accuracy is lagging as we are going down toward the profile end and profile accuracy is high on backing plate head. The cad profile diameter was 70mm, 59.11mm, 51.61mm, and 44.11mm. the closest accurate profile parameter were 0.8mm step depth, 10mm diameter tool and 1000 rpm feed rate with 67.2633mm, 60.3706mm, 50.3446mm and 46.5849mm diameter as shown in fig.5. The most immoderate profile parameter were 0.2mm step depth, 10mm tool diameter and 2000 rpm feed rate with 68.2822mm, 63.2045mm, 56.8217mm and 49.4178mm diameter as shown in fig.6.

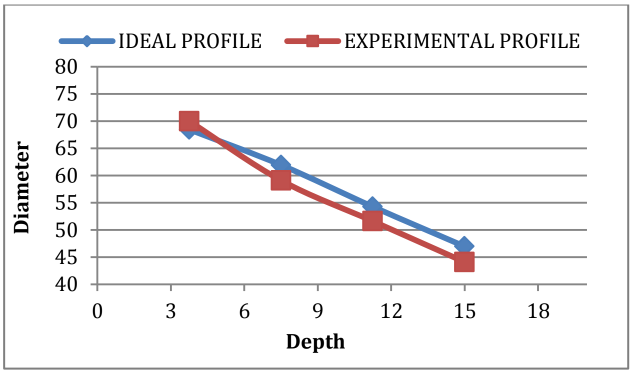

Fig.5 Attained and Cad diameter Comparison (Most Accurate)

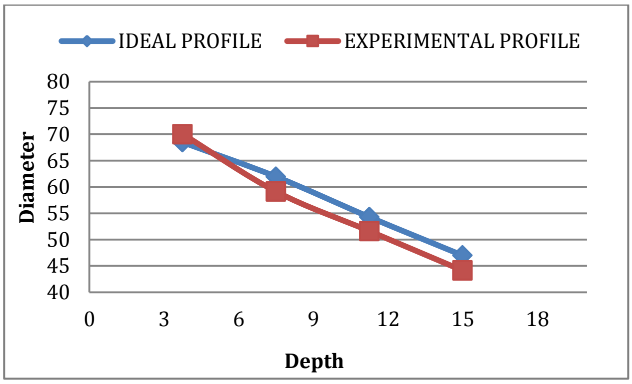

Fig.6 Attained and Cad diameter Comparison (Immoderate)

The above represented graphs showed the profile difference between the actual profile and CAD profile. The percentage error is found to be average 4 % between CAD and actual profile.

Conclusions

In this study, the effect of various parameters is investigated on roughness and profile accuracy using AA 1200 H14 Tempered aluminum blank. These parameters are step depth, tool diameter and feed rate. It is clear from the optimization of the response that for roughness most optimum solution is: step dept=.2 mm, Tool dia. =12mm, and Feed rate=1000mm/rev. and at parameter roughness approaching to 0.42µm. The tool diameter found to be most significant factor. This solution provided by desirability function optimization is quite close to optimal solution provided by RSM box-Behnken design and more influencing factor is tool diameter over feed rate and step depth. Backing plate helps in improving profile accuracy. Adding a backing plate permitted a reduction in the region of sheet bending in an area of closer to the major diameter and provides maximum accuracy to component in region.

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