

# Influence of process parameters on surface roughness in single point incremental forming using dummy sheet

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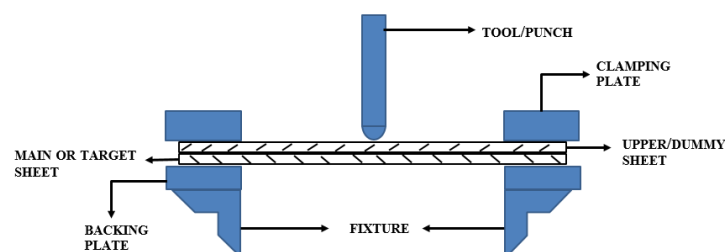
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**Abstract.** Single point incremental sheet forming (SPIF) is an advanced sheet metal forming process. It is flexible and does not require dedicated punch and die set-up for forming operation. But due to its high surface roughness, it is still not so popular in sheet metal industries. But when SPIF is performed with dummy sheet at the top of target sheet, then this limitation is eliminated to some extent. In the present paper, research work involved in experimental study on influence of process parameters on surface roughness in SPIF using dummy sheet is described. Five process parameters namely dummy sheet thickness, tool size, step size, wall angle and feed rate are considered in the present study. From the analysis of variance (ANOVA), it is found that parameters namely dummy sheet thickness, tool size, step size, and wall angle are significant and feed rate is insignificant. The surface roughness decreases with increase in wall angle, dummy sheet thickness and tool size while increases with the increases in step size.

## 1. Introduction

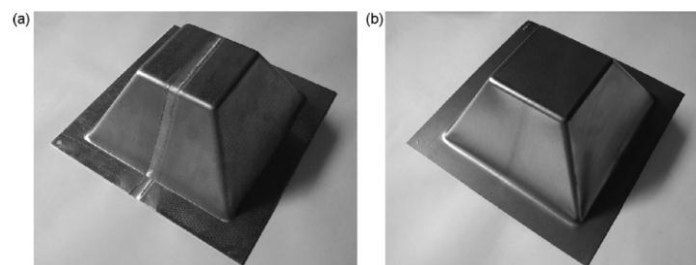
Single point incremental sheet forming (SPIF) process is advanced sheet metal forming in which the requirement of dedicated punch and die setup is completely eliminated. The product is directly fabricated from CAD model itself, thus eliminates the need of fixture and punch-die setup. It offers higher flexibility as compared to conventional sheet metal forming. The process can be performed on any 3-axis CNC milling machine. But even though with such advantages, parts produced by SPIF has high surface roughness due to waviness caused by the forming tool. Due to this limitation, SPIF is not so popular in sheet metal industries.



**Figure 1.** SPIF process using dummy sheet

However, as reported in literature when SPIF is performed with dummy sheet at the top of main or target sheet, the surface roughness is minimized to some extent. In this case all tool marks appear on

dummy sheet while smooth surface is obtained at the main or target sheet. In SPIF process using dummy sheet, two sheets are deformed simultaneously. The main or target sheet is deformed by the virtual radius of the tool (virtual tool size) which is combination of tool diameter itself followed by the curve traced by tool on the upper sheet. Figure 1 shows SPIF process using dummy sheet on the top. Skjædt et al. [1] studied SPIF process using dummy sheet in order to overcome the limitation of poor surface finish in conventional SPIF process. It was reported that when DC-04 sheet was used as dummy sheet over AA1050-H111 grade aluminium the surface of main sheet appeared to be smooth also with this combination there was increase in achievable wall angle by 5 degrees. Martins et al. [2] presented the theoretical analysis about state of stress in SPIF process. They reported that the use of dummy sheet influences formability of main/target sheet material and limits maximum achievable forming angle or wall angle. This is due to the fact that the dummy sheet virtually increases diameter of tool. The increase of this virtual tool diameter leads to an increase of meridional stress, thereby, increasing hydrostatic stress which leads to reduced formability. Alves et al. [3] compared conventional SPIF of a single sheet and SPIF using dummy sheet with the help of experimental investigation. They used DC-01 steel sheet of 0.63 mm as dummy sheet over AA1050-H111 grade aluminium. They reported that the use of dummy sheets can resolve problem of poor surface finish. The surface roughness value was very less in case of SPIF using dummy sheet as compared to the results obtained in conventional SPIF process. Also, the thickness distribution obtained after experimentation is close to the value obtained by sine law (only for higher wall angles). Silva et al. [4] used tailor friction stir welded blanks (TWB) of AA1050-H111 as sheet material for SPIF process with two different sheet thickness i.e. 1.5 mm and 2 mm. They used the dummy sheet over the welded blanks in order to protect welding seam from the rotating tool. They reported that very slight decrease in formability was observed along with good surface characteristics. A comparison is also done between conventional SPIF and SPIF using dummy sheet (Figure 2).



**Figure 2.** (a) Conventional SPIF of TWB of Aluminium AA1050-H111 with a uniform 2.0 mm thickness profile. (b) SPIF using dummy sheet [4]

Lasunon [5] investigated the influence of wall angle, step size and feed on surface roughness and reported that less step size and high wall angle is beneficial for good surface finish. Echraf and Hrairi [6] studied the influence of step size, tool size, spindle speed and feed on surface roughness and reported that bigger tool size and smaller step size give smooth surface. Influence of tool path, tool diameter and step size on the surface roughness ( $R_a$ ) was studied by Jagtap et al. [7]. It was observed that with low step size and high tool diameter  $R_a$  value decreases. Najafabady and Ghaei [8] reported that with the increase in step size, surface roughness increases.

From the review of available literature, it is found that very less research efforts have been applied to study SPIF process using dummy sheet. Influence of process parameters on surface roughness of formed parts in case of SPIF process using dummy sheet has not been reported. The present study is focused on influence of process parameters of SPIF using dummy sheet on surface roughness of formed parts. Five process parameters namely dummy sheet thickness, tool size, step size, wall angle and feed rate are considered in the present study.

The subsequent sections of this paper highlight experimental plan, results and discussion and finally conclude the present study.

## 2. Experimental Plan

All experiments of present study are performed on a 3-axis milling machine (model – Dart of M/s Batliboi Ltd., Surat, India). Experimental set-up is shown in Figure 3. The fixture as mounted on machine table is fabricated. The objective of present work is to investigate the influence of five process parameters namely dummy sheet thickness, wall angle, step size, tool size and feed rate on surface roughness ( $R_a$  value) characteristics. The experiments are designed as per Box Behnken DOE. Total 46 experiments are performed. Figure 4 depicts the formed components. The set of parameters with their levels taken are listed in Table 1. Table 2 represents the parameters held constant during experimentation. Work piece material AA1050 is taken for experimentation both for dummy and target sheet.



**Figure 3.** Experimental setup for SPIF using dummy sheet



**Figure 4.** Formed parts using SPIF with dummy sheet

**Table 1.** Process parameters and their level

S.No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Wall angle	degree	35	50	65
2	Step size	mm	0.4	0.7	1
3	Tool size	mm	6	9	12
4	Feed rate	mm/min	1000	2000	3000
5	Dummy sheet thickness	mm	0.51	0.71	0.91

**Table 2.** Values of process parameter held constant

Parameter	Unit	Value
Tool path type	NA	Contoured
Spindle speed	rpm	0
Target Sheet thickness	mm	0.91
Mouth diameter of cone	mm	110
Tool material	NA	HSS

In present experimental study, 3 levels of dummy sheet thickness is considered in order to find out the influence of dummy sheet thickness on  $R_a$  value. The surface roughness ( $R_a$ ) value is measured by using Mitutoyo surf-test SJ-310 in three distinct regions - bottom region (A), middle region (B) and top region (C). In each region eight readings are taken. The average of three regions is taken and represented as Average  $R_a$ . So total 24 reading are taken for each sample.

## 3. Results and Discussion

The  $R_a$  value is measured in three distinct regions and then average is taken. Table 3 lists the measured  $R_a$  values of experiments. The analysis of variance (ANOVA) is carried out to identify the significant variables and to quantify their effects on the response characteristics. It is necessary to find out the parameter that significantly affects the performance characteristics. The ANOVA table decomposes the variability of response characteristics into contribution due to various factors. Table 4 shows the ANOVA table for surface roughness ( $R_a$ ).

**Table 3.** Measured Surface Roughness ( $R_a$ )

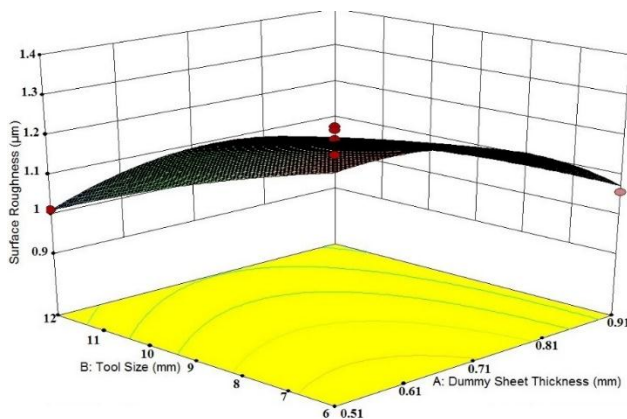
Exp. No.	Dummy sheet thickness (mm)	Tool size (mm)	Step size (mm)	Wall angle (degree)	Feed rate (mm/min)	$R_a$ ( $\mu\text{m}$ )
1	0.51	6	0.7	50	2000	1.313
2	0.91	6	0.7	50	2000	1.059
3	0.51	12	0.7	50	2000	1.013
4	0.91	12	0.7	50	2000	0.983
5	0.71	9	0.4	35	2000	0.985
6	0.71	9	1	35	2000	1.309
7	0.71	9	0.4	65	2000	1.126
8	0.71	9	1	65	2000	1.019
9	0.71	6	0.7	50	1000	1.129
10	0.71	12	0.7	50	1000	1.121
11	0.71	6	0.7	50	3000	1.271
12	0.71	12	0.7	50	3000	1.038
13	0.51	9	0.4	50	2000	1.092
14	0.91	9	0.4	50	2000	1.132
15	0.51	9	1	50	2000	1.309
16	0.91	9	1	50	2000	1.094
17	0.71	9	0.7	35	1000	1.1
18	0.71	9	0.7	65	1000	1.047
19	0.71	9	0.7	35	3000	1.039
20	0.71	9	0.7	65	3000	1.052
21	0.71	6	0.4	50	2000	1.229
22	0.71	12	0.4	50	2000	1.065
23	0.71	6	1	50	2000	1.296
24	0.71	12	1	50	2000	1.1067
25	0.51	9	0.7	35	2000	1.0777
26	0.91	9	0.7	35	2000	0.973
27	0.51	9	0.7	65	2000	1.027
28	0.91	9	0.7	65	2000	0.9947
29	0.71	9	0.4	50	1000	1.057
30	0.71	9	1	50	1000	1.261
31	0.71	9	0.4	50	3000	1.1977
32	0.71	9	1	50	3000	1.064
33	0.51	9	0.7	50	1000	1.152
34	0.91	9	0.7	50	1000	0.964
35	0.51	9	0.7	50	3000	1.0153
36	0.91	9	0.7	50	3000	1.1047
37	0.71	6	0.7	35	2000	1.229
38	0.71	12	0.7	35	2000	1.0387
39	0.71	6	0.7	65	2000	1.0643
40	0.71	12	0.7	65	2000	1.0227
41	0.71	9	0.7	50	2000	1.154
42	0.71	9	0.7	50	2000	1.178
43	0.71	9	0.7	50	2000	1.224
44	0.71	9	0.7	50	2000	1.1927
45	0.71	9	0.7	50	2000	1.2157
46	0.71	9	0.7	50	2000	1.169

From ANOVA It is found that process parameters namely tool size, dummy sheet thickness, step size and wall angle are significant parameters. Feed rate is found to be insignificant parameter. As depicted in Figure 5, with the increase in tool size,  $R_a$  value decreases. This is because with higher tool size, more contact area is covered by tool on the sheet i.e. the area of contact increases. Also, with

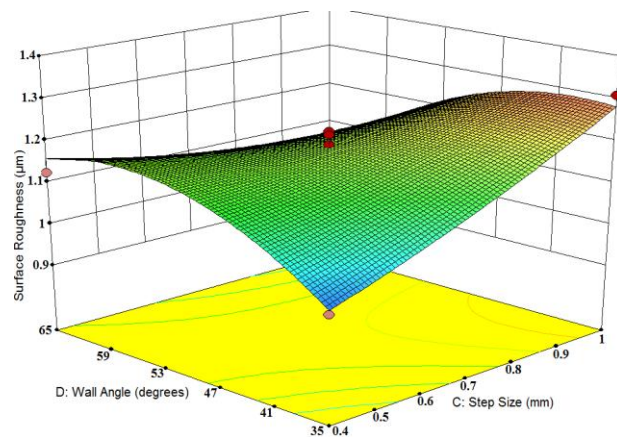
higher tool size the tool approximately covers 40% to 50% contact zone of the previous loop in the subsequent loop, thus suppressing the scallop height.

**Table 4.** ANOVA Table for Surface Roughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.42	20	0.021	18.11	< 0.0001	significant
A-Dummy Sheet Thickness	0.030	1	0.030	26.24	< 0.0001	
B-Tool Size	0.090	1	0.090	78.62	< 0.0001	
C-Step Size	0.021	1	0.021	17.98	0.0003	
D-Wall Angle	9.935E-003	1	9.935E-003	8.65	0.0070	
E-Feed Rate	1.519E-004	1	1.519E-004	0.13	0.7192	
AB	0.013	1	0.013	10.92	0.0029	
AC	0.016	1	0.016	14.15	0.0009	
AE	0.019	1	0.019	16.74	0.0004	
BD	5.528E-003	1	5.528E-003	4.81	0.0378	
BE	0.013	1	0.013	11.02	0.0028	
CD	0.046	1	0.046	40.42	< 0.0001	
CE	0.029	1	0.029	24.81	< 0.0001	
A^2	0.046	1	0.046	40.17	< 0.0001	
D^2	0.070	1	0.070	60.61	< 0.0001	
E^2	0.019	1	0.019	16.74	0.0004	
Residual	0.029	25	1.149E-003			not significant
Lack of Fit	0.025	20	1.251E-003	1.69	0.2930	
Pure Error	3.698E-003	5	7.395E-004			
Cor Total	0.44	45				



**Figure 5.** Influence of tool size and dummy sheet thickness on surface roughness



**Figure 6.** Influence of wall angle and step size on surface roughness

As the dummy sheet thickness increases,  $R_a$  value slightly increases and then decreases. The slight increase in  $R_a$  value is due to predominant effect of other parameters (like step size) than dummy sheet thickness itself. By using dummy sheet over target sheet, the virtual tool size (in terms of tool diameter) increases and as tool size increases the  $R_a$  value decreases. Figure 6 shows the influence of wall angle and step size on  $R_a$  value of target or main sheet. With the increase in step size, surface roughness ( $R_a$  value) increases. This is because surface waviness increases as step size increases. The reason for increased waviness of surface is due to increase in scallop height at larger step size [9]. Further, with the increase in wall angle,  $R_a$  value decreases. This is due to the fact that as wall angle increases the direct distance between the two subsequent loop decreases resulting in improved surface

finish. Feed rate has no influence on  $R_a$  value. This is because all the adverse effects like surface scratches and wear caused by high feed rate are completely faced by dummy sheet as also reported by Silva et al. [10]. Thus, good surface finish is obtained on target sheet. As feed rate is found insignificant in influencing surface roughness, therefore use of high feed is suggested to reduce forming time.

#### 4. Conclusion

The influence of process parameters of SPIF process using dummy sheet on surface roughness of formed part has been investigated. Five parameters namely dummy sheet thickness, step size, tool size, wall angle and feed rate are considered. The findings of the present work are enumerated as under -

- (i) Process parameters namely dummy sheet thickness, tool size, step size and wall angle are found significant in influencing  $R_a$  value of formed part (i.e. target sheet) and feed rate is insignificant.
- (ii) There is considerable influence of dummy sheet thickness and wall angle on  $R_a$  value. With increase in dummy sheet thickness and wall angle,  $R_a$  value decreases.
- (iii) As tool size (i.e. tool diameter) increases,  $R_a$  value decreases.
- (iv) With increase in step size,  $R_a$  value increases.
- (v) As the feed rate is found to be an insignificant parameter influencing  $R_a$  value, therefore high feed rate is suggested to reduce forming time.

The above findings are certainly useful in improving surface characteristics of formed part produced by SPIF using dummy sheet to make this process acceptable in sheet metal industries.

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