Research Article

The Effect Study of Parameters in (ISMF) on (Surface Roughness, Time Work and Thickness Distribution) for (AL-1060) Sheet Metal

Basheer Abd Ali Jasim Al-Obaidi[†*] and **Wissam Kadhim Hamdan**[†]

[†]Production Engineering & Metallurgy Department, University of Technology / Baghdad, Iraq

Abstract

In order to studying the factors are instrumental to the incremental deformation process is to identify the most importance factors, namely, (feed rate, stepover, forming angle), study and statement of its impact on the (surface roughness , time work and thickness distribution) As for the factors remaining have been installed such as{(thickness(0.85mm), tool path(spiral), speed(1000revlmin), tool radius(7mm), metal type(AL-1060), the type of operation(SPIF), oiling(engine oil) …. etc.). The analysis is performed using the method of conducting Taguchi (9) the experiences of mixed type as shown in the table 2.were analyzed using averages and Signal to Noise (S/N) ratio and analysis of variance(ANOVA) to study and understand the impact of factors on the cone minus product. Through analysis of variance results showed that the effect of parameters on (surface roughness and time work) was the stepover is parameter has large effect and is followed by feed rate and angle respectively. While the effect of parameter on thickness distribution was the angle is parameter that has large effect where they effect on the final thickness of the product contribution rate (92.74%) and is followed by stepover and feed rate.

Keywords: *Incremental sheet metal forming (ISMF), Design of experiment (DOE), Analysis of variance (ANOVA), Response table, Single Point Incremental Forming (SPIF)*

1. Introduction

The incremental sheet metal forming (ISMF). It is based on using of simple spherical tool, which is moved along CNC controlled tool path. It is foundation on deforming the sheet locally layer by layer. The sheet blank is fixed in sheet holder and then the tools will deform the sheet blank drawing a contour on horizontal plane, and makes step downwards and draws next contour and so on until operation is the end.

1.1 Surface Roughness.

The surface quality is a very important formed part. The surface roughness is an essential requirement in determining the surface quality of a product and widely used index of product quality and in most cases a technical requirement for mechanical products. Surface roughness is defined as the irregularities of any material resulting from machining or forming operations. It is denoted by Ra – namely, average roughness. Ra is theoretically derived as the arithmetic average value of departure of the profile from the

mean line along a sampling length. Surface roughness has been obtained in both the tool advancing direction and in the perpendicular one. The obtained values are always lower in the tool advancing direction than in the perpendicular one . So, most researchers measured the roughness perpendicular to direction of the tool movement. The surface roughness is affected primarily by the (tool radius, step size, material thickness, forming angle, feed rate, and lubricant). Roughness can be decreased by decreasing axial step size. Generally, surface roughness in incremental forming is regarded as a weak point when compared to the traditional processes. And it is important variable to be taken into account in global process evaluation because the nature of process which depends upon local contact zone that moving along entire part. (M.Durante *et al*, 2009).

1.2 Wall thickness distribution

The final thickness of a part formed by ISMF process can be estimated using the sine-law. This law was originally developed for the shear forming process. The final wall thickness (i.e. after thinning) becomes less than that of the original blank sheet and, especially under uni-axial deformation. To deform the sheet in a series of incremental steps . Wall/sheet thinning in SPIF mainly depends on the deformation/wall angle

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*Corresponding author **Basheer Abd Ali Jasim Al-Obaidi is M.Sc. Prod. Eng. Scholar and Dr. Wissam Kadhim Hamdan** is working as Assistant Professor

imposed on the sheet blank. The thinning on this failure point will be the thinning limit of the sheet metal. In terms of the thickness variations in the radial direction, the whole deformation area could be divided into three distinct parts: AB, BC and CD regions. With the increase in the distance, the thickness swiftly reduces in AB region, to a comparatively stable value in BC region. (L.jun-chao *et al*, 2010).
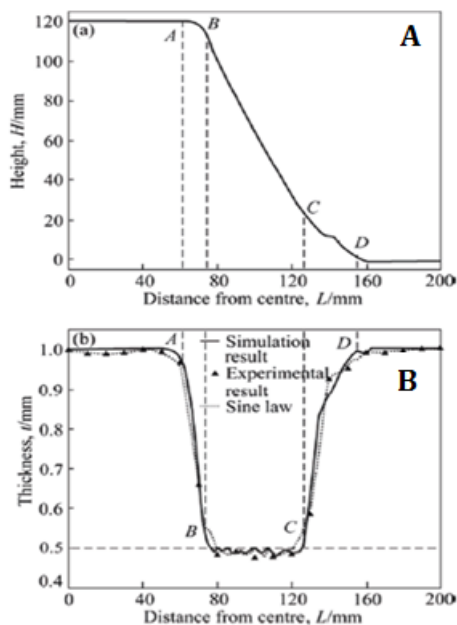

Fig. 1 Simulation result of truncated pyramid (a) longitude-sectional profile, (b) thickness comparison. (Le van sy.2009)

As showed in Fig. 1. The deformation area from point A to point D has been divided into three segments. In BC region, the thickness fluctuates slightly around 0.5 mm. However, this is not the case in AC and CD regions. The difference between them may be attributed to the different deformation characteristics. The material in BC area is mainly subjected to a pure shear deformation, while the stretching deformation and bending deformation coexist in the other two areas AB, CD.

1.3 Asymmetric (ISMF)

Several new metal forming techniques have been developed in the last few years due to advances in: 1) computer controlled machining; 2) symmetric single point forming; and 3) the development of toolpath postprocessors in (CAD) software packages. One significant outcome of this technology is the ability to form asymmetric shapes at low cost, without expensive dies. The asymmetric sheet metal incremental forming techniques discussed here can be divided into different categories. First is a method initially developed by (N.Powell and C.Andrew,1992), which was subsequently called the backward bulge method by (S.Matsubara,1994). Bambach *et al*. are also active with

this application(M.Bambach *et al,*2004). Both symmetric and asymmetric shapes can be created using this process. See Fig.2 (c) and (d). The next class includes work by (J.Jeswiet and D.young,2004) ,(T.Kim and D.Young,2004),(D.Leach *et al*,2001) , and (L.Felici *et al*,2002), all of whom have studied the application of incremental (CNC) forming technology to asymmetric shapes. See Fig.2 (a). In this process, the blank remains stationary and forming occurs during (CNC) control of the tool in a (CNC) mill.
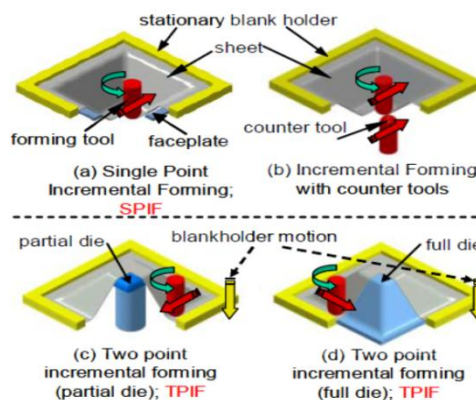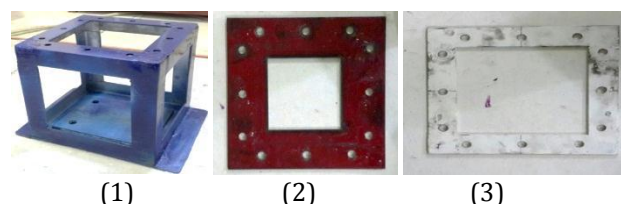

Fig. 2 Process principles of (AISF). Four variations are shown. (M.Bambach *et al,* 2004).

2. Experiment work

2.1 Designing the fixture of single point (ISMF)

It composed of three parts (1-fram; 2- backing plate; 3- sporting plat) the complete clamping system show in fig. 3.The frame fixed on the machine working table, the sporting plate holder to hold the sheet over the backing plat.

Fig.3 Show the (1-fram; 2-sporting plat; 3-backing plat)

2.2 Lubrication

The forming tool has the end-hemispherical shape, which is pressed into the metal sheet to cause the locally plastic deformation. The heat due to friction and wear of tool increases highly during the tool movement. Tool wearing and local heating influenced on the surface quality and the geometric accuracy. The tool tip was submerged in the lubricant with increasing the depth of part. In some cases it was noted that chipping was found during forming when the lubricant was poor. Fig.4. Show stages of the lubrication on the sheet work that was used in (SPIF) process.in this work used oil engine.
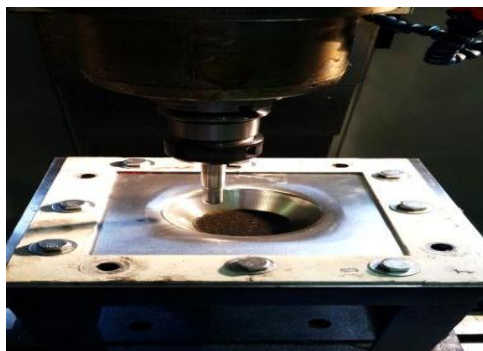
Fig.4: Shows stages of the lubrication

2.3 Design of experimental (DOE) with Taguchi approach in (SPIF)

In (SPIF) process, it is most important to determine the optimal settings of process parameters aiming at reduction of production costs, time and achieving the desired product quality. This section discusses the use of Taguchi .The influence of three forming parameters, angles (θ), feed rate (f), and step over (Δz) on average surface roughness (Ra), time deformation, and thickness distribution were analyzed on the basis of the mixed standard L9 Taguchi orthogonal array.

First, the effects of the forming parameters are angles (θ), feed rate (f), and step over (Δz) on the (SPIF) process. Three process parameters each at three levels have been decided. The process parameters are renamed as factors and they are given in the adjacent column. The levels of the individual process parameters/factors are given in Table 1.

Table 1: Design factors and their levels for the present experimental work

Factor	Parameters	:Levels		
		L1	L2	L3
A	Angles(θ)	59°	61°	63°
B	Step over (mm)	0.3	0.6	0.9
C	Feed rate(mm/min)	500	1000	1500

The process parameters were evaluated by Taguchi's method. In particular, an L9 (mixed) standard orthogonal array was employed as experimental design. In order to observe the influence degree of Control.

This orthogonal array is chosen due to its capability to unequal levels of process parameter with help of the commercial software package (MINITAB 17) (statistical software) to collect and analyze the experiential result.

Table 2 Experimental design orthogonal array of Taguchi approach

Exp. No.	Original value			Coded value		
	Angles (θ)	Feed rate (mm/min)	Step over(mm)	X1	X2	X3
1	59°	500	0.3	1	1	1
2	59°	1000	0.6	1	2	2
3	59°	1500	0.9	1	3	3
4	61°	500	0.6	2	1	2
5	61°	1000	0.9	2	2	3
6	61°	1500	0.3	2	3	1
7	63°	500	0.9	3	1	3
8	63°	1000	0.3	3	2	1
9	63°	1500	0.6	3	3	2

While determining the influence on the forming performance using the analysis of means, this analysis of means is the process of estimating the factor effects. Experimental layout was selected to satisfy the minimum number of experiments as shown in Table 2.

In a second step, is the analysis of S/N ratios to measure the quality characteristics deviating from the desired values. A greater S/N ratio corresponds to better-quality characteristics. Note a higher algebraic value of S/N ratio corresponds to better quality characteristic, i.e. to the smaller variance of the output characteristic around the desired (target) value. Based on the type of performance characteristics, Taguchi categorizes performance characteristics into three different kinds, such as; the nominal the better (NB), the smaller the better (SB), and the larger the better (LB), There are several S/N ratios available depending on type of characteristics.

In a third step, analysis of variance (ANOVA) was performed to identify the process parameters that were statistically significant. This analysis is used for both means and S/N ratio. From ANOVA table the percent of contributions of effects of control factors can be found.

In final step, the optimal combination of the process parameters was predicted. in order to identify the optimum characteristics responses which can be obtained by a particular combination of parameters in (SPIF) process.

2.4 Thickness measurement

To measure the thickness of the part, the cut was selected to desired direction that feasible the thickness measured.as show in fig.5.below is observation the parts cut. The wall thickness was measured with thickness measuring device (digital thickness gage indicator measuring range 25.4 mm and resolution 0.001 mm) as show in fig.5.below. Thickness of the final part was measured and compared with that predicted by the sine's law.

2.5 Surface roughness measurement.

The surface roughness of the samples was measured with the help of Surface Roughness Tester; pocket Surf® III I ABSOLUTE MOBILITY. Measuring ranges (Ra 0.03 μm to 6.35 μm and Rz 0.2 μm to 25.3 μm) with display Resolution 0.01 μm. The device is shown in fig.5.So this study will measure in perpendicular direction only.
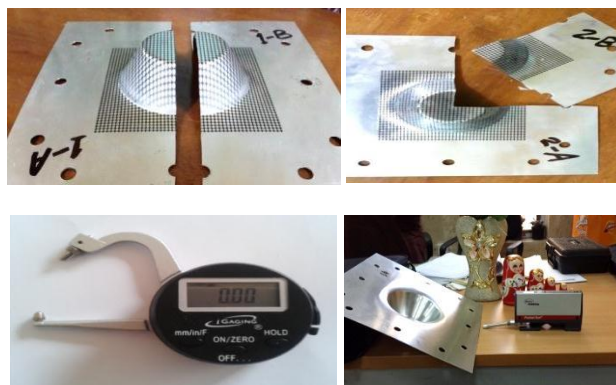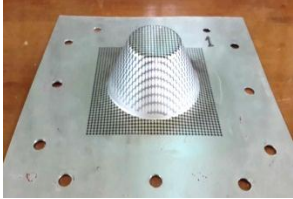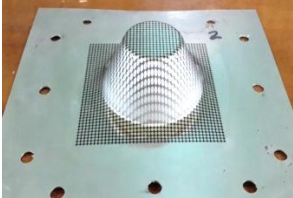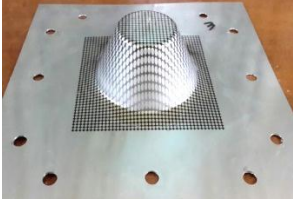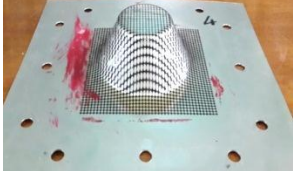

Fig.5: Rhe parts cut, and devices of (digital thickness gage, and Surface Roughness Tester)
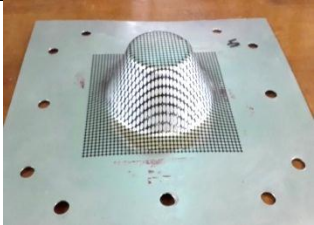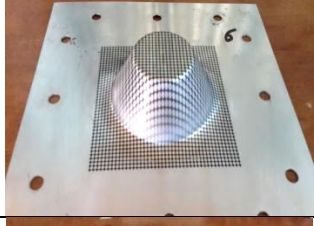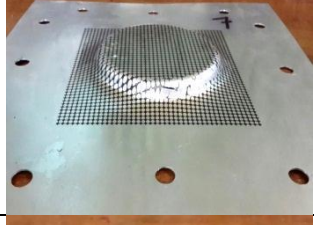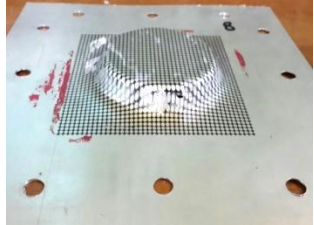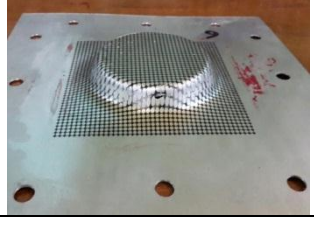
3. Result and discussion.

3.1. Effect of (SPIF) parameters on (surface roughness)

Surface roughness is a widely used index of product quality and in most cases as technical requirement for mechanical products. The quality characteristics for calculation of S/N ratio of surface roughness are taken as of lower-the-better type of the average surface roughness (Ra μm) of machined specimens measured. Table 3.shows the results obtained for all experimental work.

Table 3: shows the results obtained for all experimental work

No	θ	Feed rate	Step over	Time work	Ra	Tf	Picture of the parts
1-	59°	500	0.3	124	0.9	0.457	
2-	59°	1000	0.6	28	1.03	0.448	
3-	59°	1500	0.9	7	1.15	0.443	
4-	61°	500	0.6	68	1.01	0.425	

5-	61°	1000	0.9	12	1.12	0.416	
6-	61°	1500	0.3	27	0.99	0.428	
7-	63°	500	0.9	*	*	0.393	
8-	63°	1000	0.3	*	*	0.405	
9-	63°	1500	0.6	*	*	0.387	

3.1.1 The means of (surface roughness)

The average values of the surface roughness (main effects) for each parameter at level L1, L2 and L3 are calculated and given in Table 4. respectively. The values have been plotted in Fig.6.

Table 4: surface roughness (main effects) for each parameter at level L1, L2 and L3

No	θ	f	ΔZ	surface roughness MEAN	surface roughness S/N
1-	59	500	0.3	0.90	0.91515
2-	59	1000	0.6	1.03	-0.25674
3-	59	1500	0.9	1.18	-1.43764
4-	61	500	0.6	1.01	-0.08643
5-	61	1000	0.9	1.12	-0.98436
6-	61	1500	0.3	0.99	0.08730
7-	63	500	0.9	*	*
8-	63	1000	0.3	*	*
9-	63	1500	0.6	*	*
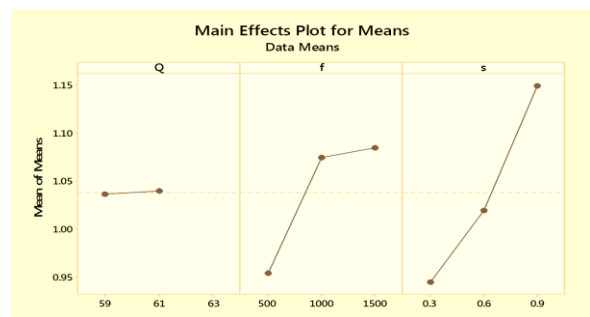
Fig.6: Main effects plot of factor effects on surface roughness

1-) (angles effect) shows the variation of surface roughness. The result shows that surface roughness is obtained when angle (61°) is used is higher. Also it is noted that surface roughness decrease with the use of angle (59°).

2-) (feed rate effect) it can be observed that the surface roughness decreases as feed rate decreases . However, the lowest value of surface roughness can be obtained with first level (500). So the feed rate have significant effect on process.

3-) (stepover Δz) shows the variation of surface roughness with respect to stepover (Δz). It can be noted that the best surface roughness is obtained when the smallest value is selected from the set parameter (0.3) which gives the lowest value of Ra. Scallop height and surface finish are two measurements that are used for characterizing surface finish. When several scallops are created in a row the peaks and valleys occur in the surface.so the surface finish directly relates to the roughness of the surface. Scallop height is one of the most important factors that have effect on surface roughness and depend on the tool path stepover (Δz) and the tool radius.

Table 5: Response table for means smaller is better

Level	θ	f	ΔZ
1	1.0367	0.9550	0.9450
2	1.0400	1.0750	1.0200
3	*	1.0850	1.1500
Delta	0.0033	0.1300	0.2050
Rank	3	2	1

From Table 5. the result of rank represents the arrangement of parameters affecting the characteristic response. The ranks indicate the relative importance of each factor to the response. The stepover (rank1) is parameter that has large effect and is followed by feed rate (rank2) and angle (rank3) respectively.

3.1.2 The signal-to-noise ratio(surface roughness)

The factors that influence the response characteristic of any process can be classified into main groups: control factors that are controllable process variables and noise factors that are uncontrollable factors which cause significant variation in response characteristics (M.Durant *et al,* 2010;Y.Kim and J.Park,2002). Fig.7.presents plots of the S/N ratio for the three control parameters angle, feed rate, and stepover studied at their levels for the surface roughness.

As is clearly seen, by using angle(59°)the sensitivity of the system to noise factors increases, the Ra response also decreases stepover and feed rate, the sensitivity of the system to noise factors increases for the surface roughness response.

1-) The S/N ratio is high when the angle (L1) is used as compared with that for angle (L2). So from this result it is noted the angle(59°) has a higher value of S/N ratio and gives higher signal and less noise and this leads to an optimum result of these parameters.
2-) Feed rate effect presents the effect of feed rate of surface roughness. Results show that the surface roughness depends on the feed rate and it has effect on Ra which is important and when feed rate decreases a high signal with less noise result
3-) The S/N ratio is a highest value for small level (level1) of stepover with high signal with less noise.. A signal to noise ratio (SNR) analysis is conducted to find

the optimal settings and factor levels.so, the level corresponding to higher S/N value is the optimum level for surface roughness. Further, from Fig.7. It can be seen that the optimal forming parameter performance for the mean (minimum) is obtained at angle (Level 1), feed rate 500 mm/rev(Level1) settings, and stepover 0.3 mm (Level 1).

Fig.7: Main effects plot for S/N ratios of factor effects on surface roughness

Table 6: Response Table for Signal to Noise Ratios of Smaller is better

Level	θ	F	ΔZ
1	-0.2597	0.4144	0.5012
2	-0.3278	-0.6206	-0.1716
3	*	-0.6752	-1.2110
Delta	0.0681	1.0895	1.7122
Rank	3	2	1

The result of rank represents the arrangement of parameters effect on characteristic response. The ranks indicate the relative importance of each factor to the response. The stepover (rank1) is parameter that has large effect and is followed by, feed rate (rank2) and angle (rank3) and this agrees with that obtained when means is calculated as shown in Table 5.

3.2 Effect of (SPIF) parameters on (time production)

This section discusses the use of Taguchi method for minimizing the time production. The quality characteristic for calculation of S/N ratio of time production was taken as of lower-the-better type. Table 7. Shows the results obtained for all experimental work.

Table7: Experimental results, mean and the corresponding *S/N* ratios for time production

No	θ	F	ΔZ	Time Production Mean	Time Production S/N
1-	59	500	0.3	124	-41.8684
2-	59	1000	0.6	28	-28.9432

3-	59	1500	0.9	7	-16.9020
4-	61	500	0.6	56	-34.9638
5-	61	1000	0.9	12	-21.5836
6-	61	1500	0.3	27	-28.6273
7-	63	500	0.9	*	*
8-	63	1000	0.3	*	*
9-	63	1500	0.6	*	*

3.2.1. The means of (time production)

The average values of the time production (main effects) for each parameter at level L1, L2 and L3 are calculated and given in Table 7. Respectively the values have been plotted in Fig .8.

Fig.8: Main effects plot of factor effects on time production

1-) (Angles effect) Fig.8.shows the variation of time production. The result shows that time production is obtained when angle (59°) is used are increases. Also it is noted that time production decrease with the use of angle (61°).

2-) (feed rate effect) it can be observed that the time production decreases as feed rate increases . However, the lowest value of time production can be obtained with last level (1500). so the feed rate have significant effect on process.

3-) (stepover Δz)fig.8.shows the variation of time production with respect to stepover (Δz). It can be noted that the lowest value of time production is obtained when the larger value is selected from the set parameter (0.9).

Table 8 Response table for means smaller is better

Level	θ	F	ΔZ
1	53.000	90.000	75.500
2	31.667	20.000	42.000
3	*	17.000	9.500
Delta	21.333	73.000	66.000
Rank	3	1	2

Table 8. Shows the result of rank represents the arrangement of parameters which affect characteristic response. The ranks indicate the relative importance of each factor to the response. The feed rate is a parameter that has large effect and is followed by stepover and angle.

3.2.2 The signal-to-noise ratio(time production)

Fig.9.shows the average signal-to-noise ratios of each parameter with respect to characteristic response.in this section, a smaller-is-better is employed to calculate the performance characteristic. From the figure it is noted that maximum S/N ratio of time production can be obtained when in feed rate level3 (1500) and this reduces the time production .Also it is noted the step over(0.9) and angle(61°) have effect on time production respectively.
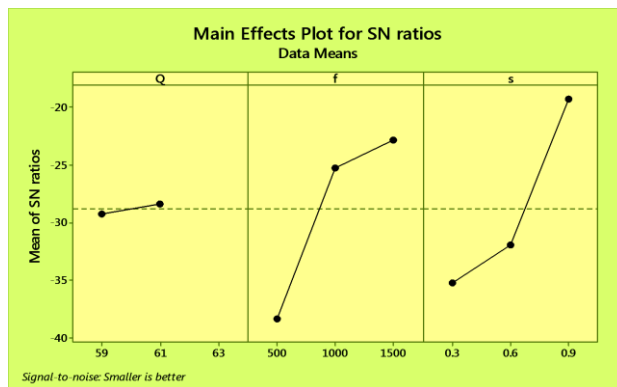

Fig.9 Main-effects for S/N 0n (time production)

FromFig.9.it is noted that the feed rate has only the significant effect on time production and the optimal forming parameter performance for S/N ratio is obtained at feed rate level3 (1500) , stepover level3 (0.9)and angle(61°). The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor.

Table 9 Response table for signal to noise ratios smaller is better for (time production)

Level	θ°	F	ΔZ
1	-29.24	-38.42	-35.25
2	-28.39	-25.26	-31.95
3	*	-22.76	-19.24
Delta	0.85	15.65	16.01
Rank	3	2	1

Table 9. Shows the rank of each parameter respect with to their effect on time production. The table includes ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistics is the highest minus the lowest average for each factor. It is noted the arrangement is as follows; stepover has high main effect and is followed by feed rate. Also the angle has smallest effect. In the figure the almost flat line variation indicates that there is a very little or virtually no effect due to angle.

3.3 Effect of (SPIF) parameters on (thickness distribution)

This section discusses the use of Taguchi method for controlling the thickness distribution of wall's part.

The quality characteristic for calculation of S/N ratio of thickness distribution was taken as of the larger-the better type. Table 10. Shows the results obtained from all experimental work.

Table 10 Experimental results, mean and the corresponding *S/N* ratios for thickness distribution

No	θ	f	ΔZ	Thickness distribution MEAN	Thickness distribution S/N
1-	59	500	0.3	0.457	-6.80168
2-	59	1000	0.6	0.448	-6.97444
3-	59	1500	0.9	0.443	-7.07193
4-	61	500	0.6	0.425	-7.43222
5-	61	1000	0.9	0.416	-7.61813
6-	61	1500	0.3	0.428	-7.37112
7-	63	500	0.9	0.393	-8.11215
8-	63	1000	0.3	0.405	-7.85090
9-	63	1500	0.6	0.387	-8.24578

3.3.1The means of(thickness distribution)

The average values of the thickness distribution (main effects) for each parameter at level L1, L2 and L3 are calculated and given in Table 10. The values have been plotted in Fig10.
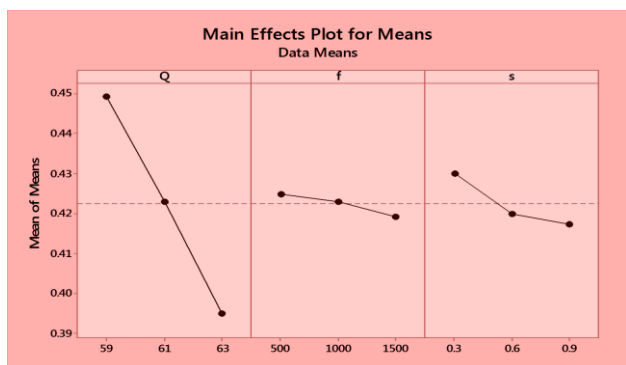
Fig.10 Main effect plot of factors on (thickness distribution)

Table 11 Response table for means larger is better for (thickness distribution)

Level	θ°	F	ΔZ
1	0.4493	0.4250	0.4300
2	0.4230	0.4230	0.4200
3	0.3950	0.4193	0.4173
Delta	0.0543	0.0057	0.0127
Rank	1	3	2

Figure 10 shows the variations of thickness distributions means with respect to the process parameters. The (angle, feed rate and step over) have significant effect on thickness distributions, from the fig.10.the angle plays a significant role in determining the thickness distributions larger thin stepover and feed rate.

Table 11 . Shows the result of rank which represents the arrangement of parameters affecting characteristic response. It is observed that the angle (rank1) is parameter that has large effect and is followed by stepover (rank2),and feed rate (rank3) .

3.3.2 The signal-to-noise ratio (thickness distribution)

Fig.11.shows the average signal-to-noise ratios of each parameter with respect to characteristic response.in this section, a larger-is-better is employed to calculate the performance characteristic. From the figure it is noted that maximum S/N ratio of thickness distribution can be obtained when in angle (59°), feed rate level1 (500) and stepover level1(0.3).
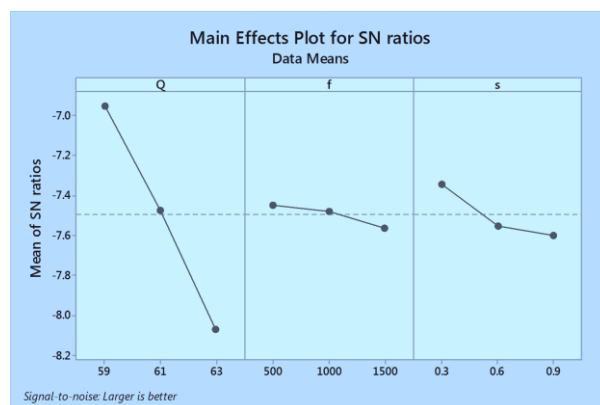
Fig.11: Main-effects for S/N 0n (thickness distribution)

Table 12. Shows the result of rank which represents the arrangement of parameters affecting characteristic response. The ranks indicate the relative importance of each factor to the response. The angle is a parameter that has large effect and is followed by feed rate and steepover. Therefor we will employ study on the effect of angel on the failure of part production.

Table 12 Response table for signal to noise ratios Smaller is better

| Level	θ°	F	ΔZ
1	-6.949	-7.449	-7.341
2	-7.474	-7.481	-7.551
3	-8.070	-7.563	-7.601
Delta	1.120	0.114	0.260
Rank	1	3	2

3.3.3 Analysis of variance for (thickness distribution)

From the (ANOVA) analysis of the means in table 13. the results show that angle plays a significant role in controlling thickness distributions of wall part, Furthermore, the stepover and feed rate are non-significant parameters.

Table 13 ANOVA analysis for means for thickness distribution

Source	DF	Seq ss	Adj MS	F	P	Percent Contribution
θ°	2	0.004430	0.002215	149.87	0.007	92.74%
F	2	0.000050	0.000025	1.68	0.374	1.04%
St	2	0.000268	0.000134	9.05	0.099	5.60%
Residual error	2	0.000030	0.000015			0.62%
Total	8	0.004776				100%
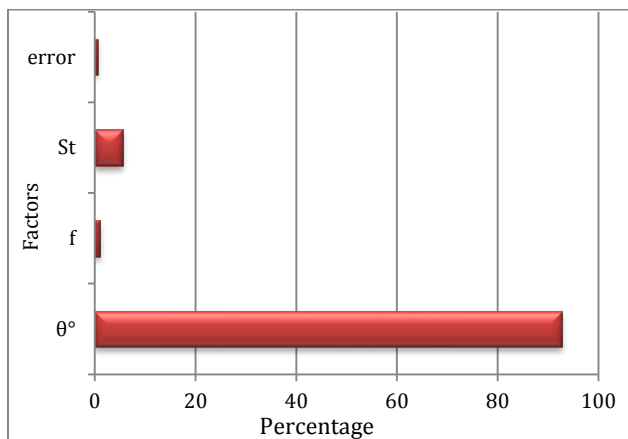
Fig.12: Percentage contribution of means for thickness distribution

Fig.12. represents the percent of contributions of effects of control factors. From the figure it is noted that the angle is a significant factor and has most effect on controlling thickness distribution with percentage contribution of (92.74%) and is followed by the step over (5.60%) and feed rate (1.04%). Therefor we will employ study on the effect of angel on the occur failure of part production.

Conclusion

1-) A mixed standard (L9) orthogonal array and analysis of means, signal-to-noise (S/N) and variance (ANOVA) were employed to analyze the effect of (SPIF) process parameters, by using Taguchi method for designing a robust experiment.

2-)The result show that the stepover (rank1) is parameter that has large effect and is followed by feed rate (rank2) and angle (rank3) respectively on the surface roughness

3-) The ranks indicate the relative importance of each factor to the response, the feed rate is a parameter that has large effect and is followed by stepover and angle on the time work.

4-) The results show that angle plays a significant role in controlling thickness distributions of wall part with percentage contribution of (92.74%), Furthermore, the stepover and feed rate are non-significant parameters.

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