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Oil Lubrication Effected On Roughness And Profile Error In Single Point Incremental Forming Product

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ABSTRACT

The single point incremental forming process (SPIF) is a novel, economy and flexibility process, which suited for sheet metal prototyping, customized product with complex shapes and low volume sheet metal product applications, because it's lower cost process which can produced sheet metal part without any used of die. They used a simple tool consist of rotating forming tool with hemispherical end, fixture and CNC milling machine. The process principle is producing a series of locally deformed on a sheet metal blank by a hemispherical tool that press and travel on the blank follow the CNC toolpath to form a complex sheet metal component shape. Then it's comfort to adjust the part's geometry by changing toolpath. The purpose of this research work is to study the influence of oil lubricant on the SPIF process parameters that affected to the surface roughness of St 37 steel by SPIF. The various combinations of oil and process parameters such as feed rate, step size, step depth, speed and tool radius were employed. The 2k factorial experiment design and Response surface methodology (RSM) design was applied to develop a mathematical model of the above parameter combination on the surface quality of the formed part. The surface roughness of formed parts was measurement by a surface roughness meter and the profile was measurement by optical 3D scan.

Keywords: Single Point Incremental Forming, Sheet forming, Incremental forming, Formability, Lubrication

INTRODUCTION

Single Point Incremental Forming (SPIF) process is a latest sheet metal forming technique approach for manufacturing of a sheet metal component. This process allows the manufacturer to produce the shell-like sheet metal components without using any expensive die. The SPIF process has been developed, for the first time, by Powell and Andrew [1]. The SPIF process principle is a sheet metal blank locally deformed by using a small diameter "hemispherical head" forming tool in comparison with the dimensions of the sheet metal blank. The process performed on a CNC milling machine, the sheet metal blank is clamped firmly on the rig, then forming tool is press and travel on the sheet metal blank follow the CNC toolpath to formed a complex sheet metal component shape. The process features have benefits not only to reduced forming forces, enhanced formability and process flexibility, but also great potential to achieve economic payoff for the individual production, small batch production and rapid prototyping. Their process tools consist of rotating forming tool with hemispherical head, fixture and CNC milling machine (see Fig. 1). Though the SPIF process is used to produce a customized or rapid sheet metal prototyping, the part's quality such as the geometry error, roughness and formability is not satisfied for some application for example, the outer panels of one car or aircraft or taillight bracket and the rapid mould for small lot plastic injection parts. (see Fig. 2) Due to its characteristic, the low geometric accuracy and surface roughness still remains the major issue of ISF, which significantly limits the industrial application of this SPIF process. Several studies have been carried out to investigate the influence of process parameters on surface quality, geometric accuracy, forming forces, thinning and sustainability. There are a lot of affecting parameters to geometric accuracy such as tool speed, side overlap and step depth, tool radius and feed rate. And the most research studied are direction to improved the geometry, it seems to be closed to successes. But the researchers yet have not reached any agreement regarding the effects on surface roughness. From investigation, high surface roughness is a result from high traveling speed and contact pressure of tool on raw material surface, then the lubricant is applied to improved surface roughness. Oil and grease are mostly spending as lubricant in sheet metal forming processes to increase the surface quality of the final product. In the past studied, it is agreed that there is a positive effect of oil lubricate in Single point incremental forming (SPIF), namely in the surface roughness. It is interesting to note that even though some studies have shown that the surface finish improves when lubrication is used, other shows negative effect of lubrication on formability. Thus, it is important that the effect of lubrication on surface roughness and geometry accuracy of the SPIF process should be studied. In this study is deeply focused to the oil lubricated effect on the surface roughness and profile error of the "St 37 / SS400 steel SPIF final product". The study involves the influence of the oil lubrication on other variable parameters such as tool size, tool rotational speed, feed rate, tool step side, tool step depth and sheet thickness, that provides the best surface finishing. The 2^k factorial experimental design was used to analyze the interaction between each parameter. The purpose of this research work is to study the influence of oil lubricant on the SPIF process parameters that affected to the surface roughness of St 37 steel by SPIF. The various combinations of oil and process parameters such as feed rate, step size, step depth, speed and tool radius were employed.

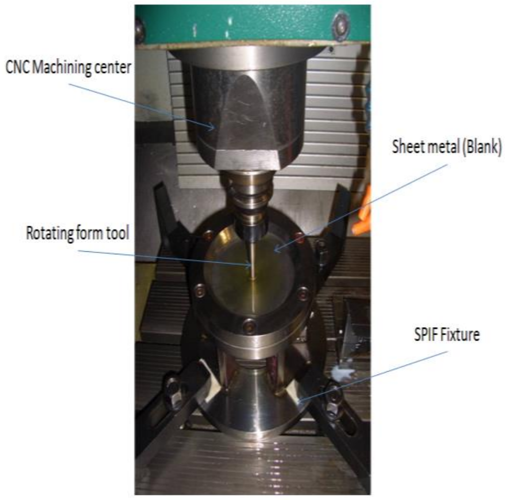

Figure 1. CNC Milling Machine and fixture in performing SPIF process

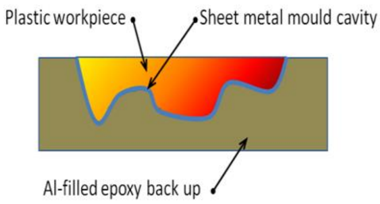

Figure 2. The new concept method for rapid mould

LITERATURE REVIEWS

Now a day, the SPIF process is still under development. A large number of studies are conducted and reported to improve formability and part geometry accuracy, but a few researches were contributed to the inner surface roughness. The inner surface roughness of SPIF part is hard to predict by mathematic and contact mechanic theory. V. Oleksik (2010) had research on the surface quality of the medical implants obtained by SPIF process. And highlighted the factors that influence surface quality are including of the initial roughness of the punch, the punch diameter, and the friction coefficient between the punch and the blank. [2] L.C.C. Cavaler, et., al. (2010) verified the resulting surface roughness of parts formed by the SPIF process for an AISI 304 austenitic stainless steel. The results found indicate that Rz roughness decrease with the increase of the vertical depth and with the use of coating tool [3] H. Wei et al. (2019) had investigated the processing effects upon the roughness of interior surfaces and on the friction indicator at the tool/sheet interface during SPIF forming of an aluminum sheet. The result had demonstrated that roughness in general linearly increases with an increase in the friction indicator because the sheet abrasion correspondingly increases. [4] S. Gatea and H. Ou (2021) was found that the surface roughness changes with the deformed part height and rough surface could be produced in the region of high equivalent stress and low equivalent plastic strain. Such a surface roughness and equivalent stress and plastic strain correlation has a clear implication to the design and the surface quality of sheet parts made by SPIF. [5] S. M. Najm and I. Paniti, (2021) demonstrated that tool materials together with tool surface (Ra) are playing a significant importance role affecting the sheet surface roughness (Ra). Whereas tool roughness Rz was the critical parameter effected on the Rz of the product. Also, there was a significant positive effect of tool geometry on the sheet surface roughness. [6]

M. Ham and J. Jeswiet, (2008) use of a Box-Behnken design analysis to determine the dimensional accuracy of this process. They allows for determination of how the interested factors (material type, material thickness, formed shape, tool size, and incremental step size) affect the dimensional accuracy. [7] G. Ambrogio et al. (2012) found that, incremental sheet forming at very high feed rates to strongly reduce processing time. [8] Y. Li et al. (2015) investigate how different process parameters (step down, sheet thickness, tool diameter and wall angle) affect the consumed energy by Box-Behnken design analysis. And proposed that, the lower deformation energy, the higher geometric accuracy. The deformation energy heavily depends on the sheet thickness, it could reduce by increasing step-down size or decreasing the wall angle. It was concluded that the geometric quality is largely determined by the quadratic effect of wall angle, the linear effect of sheet thickness and the interaction effect of thickness and step down. [9] B. Lu et al. (2016) report work in cranial plate manufacturing using SPIF process. The results show that satisfactory cranial shape can be achieved with sufficient accuracy and surface finish by using a feature based tool path generation method. [10] A. Mulay et al. (2017) and M. Honarpisheh et al. (2018) study the effect of SPIF process parameters such as, spindle speed, feed rate, step depth, tool diameter and sheet thickness on surface roughness and maximum forming angle. ANOVA test shows that step depth, tool diameter has a significant effect on the surface roughness and formability. The average surface roughness is increase with increased step depth and decreased tool diameter, the maximum forming angle is decrease with increased step depth and tool diameter. [11, 12, 13] R.B. Azhiri, et al (2020) proposed that ball nose tool significantly enhances the formability and surface quality due to conversion of sliding friction to rolling type. [14] S. M. Najm and I. Paniti, (2021) Forming tool characteristics such as tool materials, tool shape, tool end/corner radius, and tool surface roughness played a key role in all the predictions and their effect on the final product surface roughness. tool materials, together with tool surface (Ra), are playing a significant importance role, affecting the sheet surface roughness. Whereas tool roughness was the critical parameter effected on the roughness of the product. Also, there was a significant positive effect of tool geometry on the sheet surface roughness. [6]

Lubrication has been primarily used in SPIF to reduce tool wear and recently used in order improve the surface finish of SPIF formed part. Hussain et, al (2008) investigate the suitable tool and lubricant, which can be employed to form a commercially pure titanium (CP Ti) sheet by negative incremental forming. The effect of each combination of tool and lubricant on the quality of the formed surface was studied by measuring the surface roughness and examining the surface, interaction between the sheet and tool in the presence of a particular lubricant was examined, proper surface coating of the sheet-blank is an essential pre-requisite before forming. With the suggested lubrication method, the CP Ti components having good surface quality can be realized by using the surface-hardened high speed steel (HSS) tool and the paste of molybdenum disulphide (MoS2) with petroleum jelly in a specific proportion.[15] Kittiphat et, al (2011) had studied the effect of five lubricants such as, coconut oil, hydraulic oil SAE 46, synthesis drawing oil, grease and a mixture of hydraulic oil SAE 46 and MoS_2 (4:1) on the surface roughness of SS 400 steel SPIF part. The result shown the mixture of hydraulic oil and MoS_2 gave the best surface roughness, inferior were the drawing oil and the Thailand coconut oil. The third was SAE 46oil, it gave the roughness value nearly to the drawing oil and the coconut oil and the grease gave the worst surface roughness. [16] Nelson et.al. (2015) was evaluate the influence of the type of lubricant used in SPIF process, particularly on aluminum 1050 and DP780 steel sheets, in what concerns the surface quality of final parts. To do so, tests were performed employing a range of distinct lubricants. Roughness tests were conducted to evaluate surface quality. Results show opposite trends for aluminum and steel in the sense that lubricants that guarantee better results in aluminum proved to have worse results in steel and vice-versa. [17] Diabb et, al. (2017) investigating the performance that sunflower and corn oils, added with 0.0125, 0.025, 0.05 and 0.1 wt% of SiO2 nano particles, have when these are used as lubricants during Single Point Incremental Sheet Forming (SPIF) process of 6061 aluminum sheet alloys. The Stribeck curve was used to address the influence that the reinforced lubricants have on the friction and roughness values attained during SPIF process of the aluminum alloy samples. Experimental results showed a significant surface wear reduction when 0.025 wt% of SiO2 nano particles are added into the vegetable oils. [18] Kishore et, al. (2017) study a polycrystalline Copper sheet was incrementally formed to a truncated conical geometry using different lubrications till fracture. The effect of lubrication on the surface roughness was studied. The lubrication conditions had no significant effect on the formed grain size or shape.[19]

MATERIAL AND METHOD

The material used for this study is St 37 / SS400 steel which is a wide application in sheet metal industry in particular in the automotive industry. St 37 is a kind of low carbon steel with carbon content of 0.20%. It's not as strong as common ASTM A36, but it is also widely applied by everyday uses and structural applications where high strength is not so important. It has a relative fair ductility and Cheap price. The blank material were 0.8 and 1.5 mm thickness cutting form a large sheet 1200 mm*2400 mm by plasma to blank diameter of 165 mm (see Fig. 3) and mechanical property showed in Table 1.

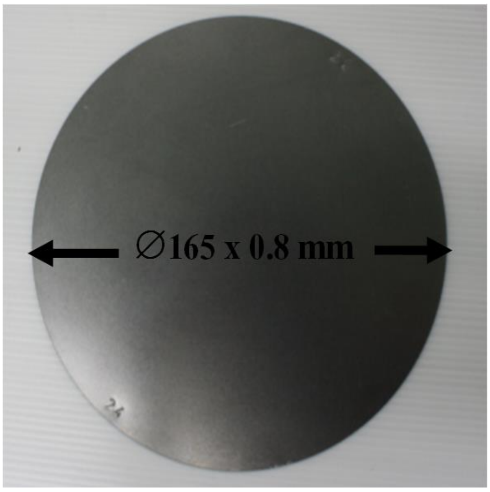

Figure 3. St 37 steel blank material

Table 1 The mechanical property of St 37 steel.

	Tensile strength [Nmm-2]	Yield stress [Nmm-2]	% Elongation [mm/mm]
Ave (3 samples)	354.61	271.33	19.94

Table 2 The Chemical property of St 37 steel

	Chemical Composition							
	C	Si	Mn	P	S	Cr	Ni	N
Ave (3 samples)	0.19	0.0005	0.03	0.05	0.06	-	-	0.008

Tool material is harden HSS 65 HRc, 10 mm diameter, grinding to specific profile hemispherical / ball end radius 5 mm and then lapped with 3 micron SiC for 3 hour, and after each experimental the tool was lapped again. The SPIF experimental were conducted on 3-axis CNC milling machine Bridgeport VMC600X, conreoller Fanuc 18i (Fig. 4). The movement of the tool is controlled through coded instructions processed by a computer system. The tool has movement along x, y, and z axes that provide easy tool movement for the complex geometries. The sheet metal always flows in the direction of tool movement. The tool follows the contour path with center to edge and spiral depth according to the coded instruction in the CNC part program. The toolpath programming was carried out at the Siemens UG NX 4 / CAM software. The forming fixture consists of the base plate, vertical rib, top plate, blank holder ring, bolts, and nuts as shown in Fig. 1. It is designed such that it should not lose rigidity due to vibrations during forming. For the current investigation, the hexagonal cone was used. The geometrical aspects are shown in Fig. 2. It has apex cone angle 40^{o}. The major diagonal of the cone is 90 mm, the radius of the edge is 5 mm. The total height of the cone is 45 mm. The blank was clamped at the periphery by a blank holder. (see Fig. 1)

Figure 4. The3-axis CNC milling machine (Bridgeport VMC600X)

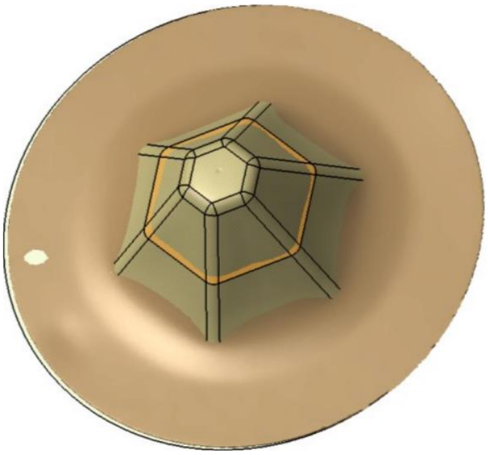

Figure 5. SPIF workpiece sample 3D geometry

In this experiment, the interaction between oil lubrication and process parameter were investigate. 2^k Experimental Design was designed to demonstrate that relationship which affected to inner surface roughness and geometry error of hexagonal cone shell workpiece. The Fixed parameter (Table 3) are tool diameter, toolpath strategy and volume of SAE 46 oil that used as lubricant. Since there are a large number of SPIF parameters were contributed, to reduce the complexity of the experimental some parameters were neglected.

The Full Factorial 2^k experimental design was used, by 5 variable parameters and two levels as shown in Table 2. So, the experiment is 2 level full factorial, 3 replicates, then the 96 experimental were random by statistical program “minitab”. The two levels in the experiments are designated as high (+) and low (-). Each setting of high or low is based on the previously work in SPIF Process at Kasetsart University and King Mongkut’s University of Technology North Bangkok.

Table 3 Fixed parameters in SPIF experimental

No.	Parameter	Detail
1	Lubricant	5 cc. SAE 46 Oil
2	Sheet material	St 37 ∅165 mm.
3	Tool material / size	10 mm Harden HSS
4	Toolpath	Center to edge traveling

Table 4 Variable parameter

No.	Independent parameter	Low level(-)	High level (+)	Unit
1	A = Feed Rate	3142	7280	mm/min
2	B = Size Overlap	1.5	3	mm
3	C = Step Depth	1.5	3	mm
4	D = Speed	100	200	rpm
5	E = Sheet Thickness	0.8	1.5	mm

The toolpath was generated by UG NX-4 as a repeated spiral center to edge traveling until the final profile was finish, and its directions were accordingly to avoid the sliding movement. The 5 cc Shell SAE 46 oil was spread on the blank surface before forming as a lubrication to avoid the friction between tool/sheet interfaces and improve process characteristics. Lubrication also enhances the functionality of the process such as heat dissipation, friction, and tool life too.

EXPERIMENTAL AND STATISTICAL ANALYSIS

After the random experimental in SPIF forming, the sample of SPIF formed part is shown in Fig. 6. The sample was measured it’s profile error by an optical 3D scan, the data of 3D scan (Fig. 7) was compared with the 3D CAD file of the idea profile. Then the profile error and wall thinning were calculated. The samples were measured it’s surface roughness by the roughness profilometer. The profile error data, wall thinning and surface roughness were analyzed by Minitab

Figure 6 Demonstrate the experimental sample

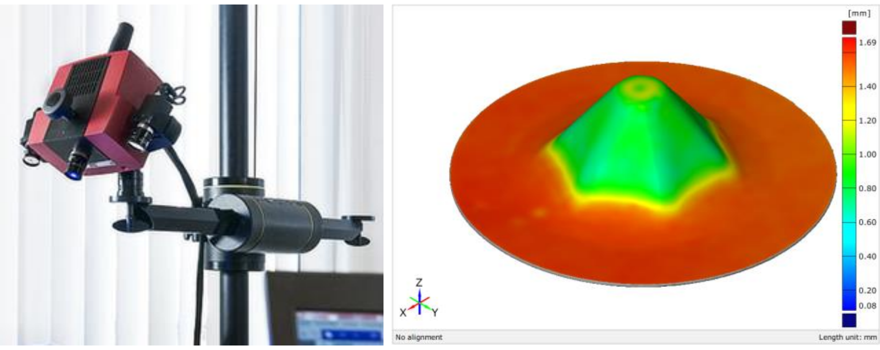

Figure 7 An optical 3D scan of the SPIF part sample

STATISTICAL ANALYSIS

To convenient, the roughness was divided into 5 ranges as shown in Table 5. The analysis of the responses inner surface roughness (Ra) is using analysis of variance (ANOVA) at 95% confidential or 0.05(α) significant. The analysis of results was done using the software.

Table 5 Range of roughness and roughness value

Range of roughness	1	2	3	4	5
Roughness value[micron]	<0.8	0.8-1.6	1.6-3.2	3.2-6.3	>6.3

The ANOVA test was performed to evaluate the statistical significances of the fitted regression model and factors involved there in for the response factors. The ANOVA indicated that the model is significant at $p < 0.05$. And the interaction of each parameter that affected to wall thinning, profile error and surface roughness was shown in Fig. 8 to Fig. 11.

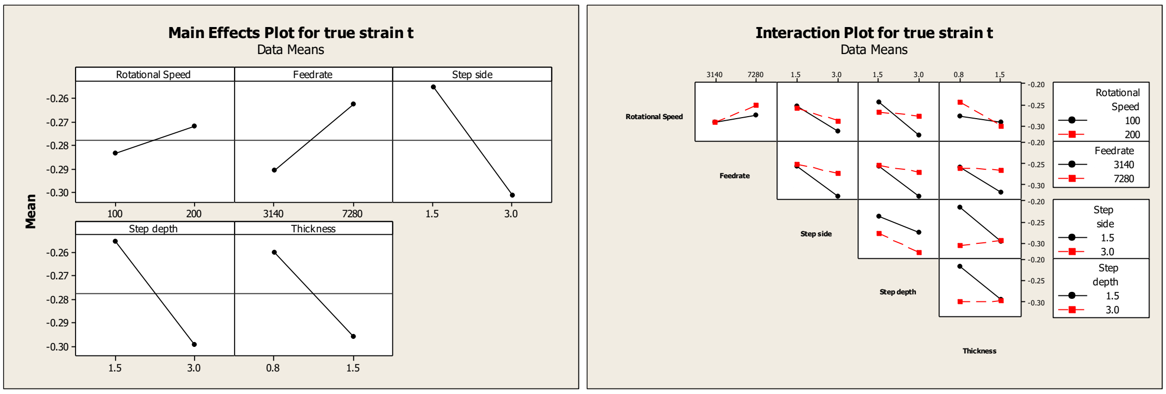

Figure 8 The statistical analysis result (Wall thinning)

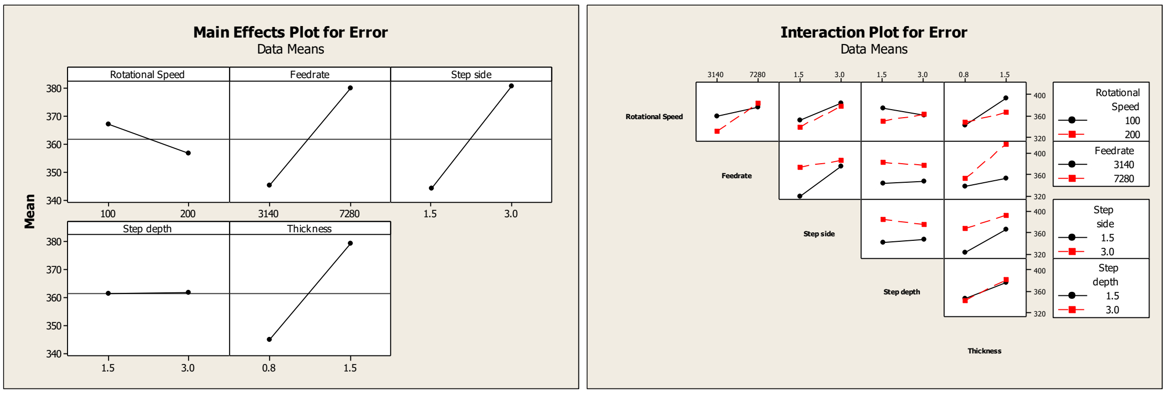

Figure 9 The statistical analysis result (Profile error)

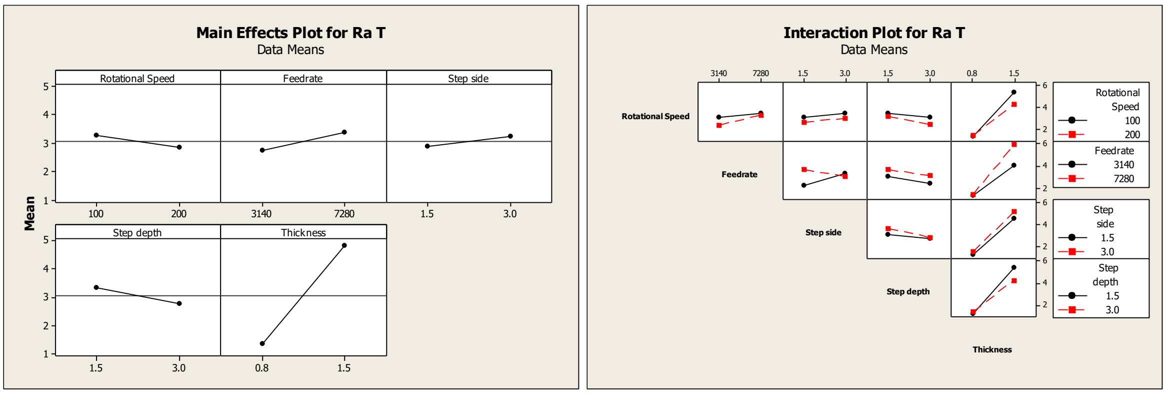

Figure 10 The statistical analysis result (Transverse surface roughness)

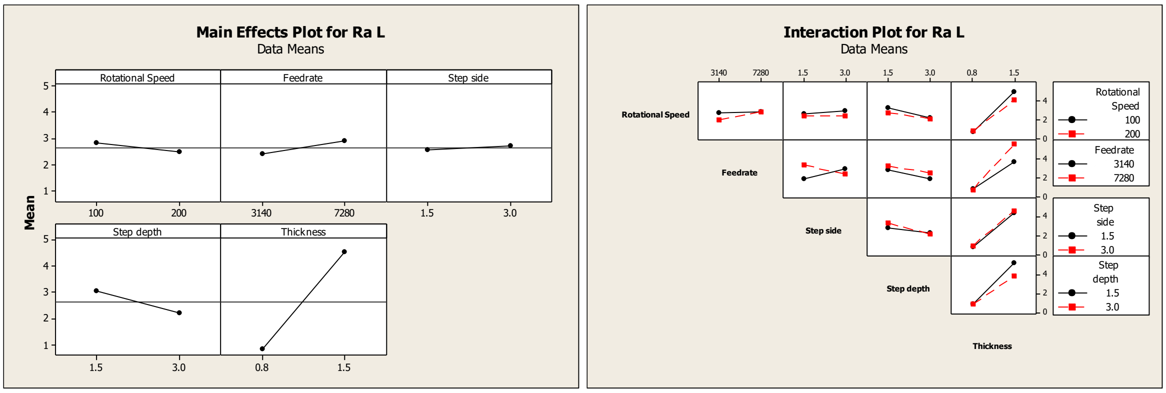

Figure 11 The statistical analysis result (Longitudinal surface roughness)

RESULTS

The experiments were conducted according to the run order of design random matrix and the corresponding profile error, wall thinning and surface roughness results were noted. The goal of this investigation is to studied the combination of SPIF process parameters on oil lubrication to SPIF sheet metal formed part without any defects. An analysis of variance (ANOVA) and main effect and interaction plots of the parameter effect were shown in Fig. 8 to Fig. 11. For the wall thinning rotation speed, feed rate, step depth, step side and sheet thickness has a strongly significant effect. The average wall thinning is found to thicker with an increase in rotational speed and feed rate, and seam to thinner with an increase in step dept, step side and sheet thickness, whereas the profile error and surface roughness tend to be in the same direction, but had a stronger effect to profile error than surface roughness, increasing rotational speed decreased profile error and surface roughness, increasing feed rate, step side and sheet thickness, increased profile error and surface roughness. But increasing step depth, improved surface roughness, a few declined profile error.

The interaction affected to wall thinning, rising rotation speed and feed rate, reduced wall thinning (thicking). The interaction of rotational speed to step side, step depth and sheet thickness, increasing rotational speed, step side, step depth and sheet thickness, improved wall thinning. The interaction of feed rate to step side, step depth and sheet thickness, the interaction of step side, to step depth and sheet thickness, the interaction of step depth and sheet thickness, were the same trend. For the profile error and surface roughness are corresponding trend, rising rotation speed, feed rate, step side, step depth and sheet thickness decreased the reduced wall thinning, SPIF quality, as shown in the Fig. 8 to Fig. 11.

So, the experiment could not clarify reviews the effect of oil lubrication to the wall thinning, profile error, and surface roughness. The in process investigated, the worst surface roughness SPIF part shown a lot of small metal chip in the oil on the SPIF formed part, the better surface roughness SPIF part shown a few of small metal chip in the oil on the SPIF formed part. The metal chips can also damage to HSS tool together as shown in Fig.12.

Figure 12 Surface roughness on SPIF part and HSS tool.

DISCUSSION AND CONCLUSIONS

The SPIF main parameters that affected to wall thinning, profile error and surface roughness were composed of lubrication, rotational speed, feed rate, step side, step depth and sheet thickness. The interaction between each parameter, which taken from the 2^k full factorial design and ANOVA were demonstrated that all parameters had an interaction effected to the SPIF quality as in discussion. H. Wei et al. (2019) had investigated the processing effects upon the roughness of interior surfaces and on the friction indicator at the tool/sheet interface during SPIF forming of an aluminum sheet. The result had demonstrated that roughness in general linearly increases with an increase in the friction indicator because the sheet abrasion correspondingly increases. [4] S. Gatea and H. Ou (2021) was found that the surface roughness changes with the deformed part height and rough surface could be produced in the region of high equivalent stress and low equivalent plastic strain. Such a surface roughness and equivalent stress and plastic strain correlation has a clear implication to the design and the surface quality of sheet parts made by SPIF. [5] S. M. Najm and I. Paniti, (2021) demonstrated that tool materials together with tool surface (Ra) are playing a significant importance role affecting the sheet surface roughness (Ra). Whereas tool roughness Rz was the critical parameter effected on the Rz of the product. Also, there was a significant positive effect of tool geometry on the sheet surface roughness. [6] S. M. Najm and I. Paniti, (2021) Forming tool characteristics such as tool materials, tool shape, tool end/corner radius, and tool surface roughness played a key role in all the predictions and their effect on the final product surface roughness. tool materials, together with tool surface (Ra), are playing a significant importance role, affecting the sheet surface roughness. Whereas tool roughness was the critical parameter effected on the roughness of the product. Also, there was a significant positive effect of tool geometry on the sheet surface roughness. [6] Kishore et, al. (2017) study a polycrystalline Copper sheet was incrementally formed to a truncated conical geometry using different lubrications till fracture. The effect of lubrication on the surface roughness was studied. The lubrication conditions had no significant effect on the formed grain size or shape.[19]

From this study it can be concluded that the oil lubricants spreading on the sheet metal before SPIF forming process may be unsuitable, because the chip form abrasive between tool and sheet are accumulate in the oil. The chip changes the wear behavior of tool-sheet interface (2 body abrasive) to tool-chip-sheet interface (3 body abrasive) which acerated wear of sheet and lead to the poor surface roughness.

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REFERENCES

[1] Powell NN, Andrew C (1992) Incremental forming of flanged sheet metal components without dedicated dies. In Proc of the Institution of Mechanical Engineers (IMECHE) part B. J Eng Manuf 206:41–47.

[2] V. Oleksik, A. Pascu, C. Deac, R. Fleacă, O. Bologa, G. Racz, (2010) Experimental study on surface quality of medical implants obtained by single point incremental forming. Int J Mater Form (2010) Vol. 3 Suppl 1:935 938.

[3] L.C.C. Cavaler, L. Schaeffer, A.S. Rocha, F. Peruch (2010) Surface roughness in incremental forming of AISI 304L stainless steel sheets. Far East Journal of Mechanical Engineering and Physics, Volume 1, Number 2, 2010, Pages 87-98.

[4] S.M. Najm, I. Paniti, (2021) Predict the Efects of Forming Tool Characteristics on Surface Roughness of Aluminum Foil Components Formed by SPIF Using ANN and SVR. International Journal of Precision Engineering and Manufacturing (2021) 22:13–26.

[5] H. Wei, G. Hussain, A. Iqbal, Z. P. Zhang (2019) Surface roughness as the function of friction indicator and an important parameters-combination having controlling influence on the roughness: recent results in incremental forming. The International Journal of Advanced Manufacturing Technology (2019) 101:2533–2545.

[6] S. Gatea, H. Ou, (2021) Surface roughness analysis of medical grade titanium sheets formed by single point incremental forming. The International Journal of Advanced Manufacturing Technology, 2021.

[7] M. Ham, J. Jeswiet, Dimensional Accuracy of Single Point Incremental Forming, Int J Mater Form (2008) Suppl 1:1171 –1174.

[8] Giuseppina Ambrogio, Luigino Filice, Francesco Gagliardi, Improving industrial suitability of incremental sheet forming process, Int J Adv Manuf Technol (2012) 58:941–947.

[9] Yanle Li, Haibo Lu, William J. T. Daniel, Paul A.,Meehan, Investigation and optimization of deformation energy and geometric accuracy in the incremental sheet forming process using response surface methodology, Int J Adv Manuf Technol (2015) 79:2041–2055.

[10] B. Lu, H. Ou, S. Q. Shi, H. Long, J. Chen, Titanium based cranial reconstruction using incremental sheet forming, Int J Mater Form (2016) 9:361–370.

[11] A Mulay, B.S. Ben, S. Ismail, A. Kocanda (2017) Experimental Investigation and Modeling of Single Point Incremental Forming for AA5052-H32 Aluminum Alloy. Arab J Sci Eng (2017) 42:4929–4940.

[12] A Mulay, B.S. Ben, S. Ismail, A. Kocanda (2017) Experimental investigations into the effects of SPIF forming conditions on surface roughness and formability by design of experiments. J Braz. Soc. Mech. Sci. Eng. (2017) 39:3997–4010.

[13] M. Honarpisheh, M. Mohammadi Jobedar, I. Alinaghian (2018) Multi-response optimization on single-point incremental forming of hyperbolic shape Al-1050/Cu bimetal using response surface methodology. The International Journal of Advanced Manufacturing Technology (2018) 96:3069–3080.

[14] R.B. Azhiri, F. Rahimidehgolan, F. Javidpour, R.M. Tekiyeh, S.M. Moussavifard, A.S. Bideskan (2020) Optimization of Single Point Incremental Forming Process Using Ball Nose Tool. Experimental Techniques (2020) 44:75–84.

[15] G. Hussain, L. Gao, N. Hayat, Z. Cui, Y.C. Pang, N.U. Dar (2008) Tool and lubrication for negative incremental forming of a commercially pure titanium sheet. Journal of materials processing technology 203 (2008) 193–201.

[16] K. Rattanachan, S. Mahatanabordee, Ch. ChungChoo (2011) The affected of lubricant to surface roughness of sheet metal part forming

by SPIF Process, The 24th International Congress on Condition Monitoring and Diagnostics Engineering Management (COMADEM2011) Stavanger, Norway from May 30, 2011 to June 1, 2011.
[17] Nelson G.A., JoãoSá F., Ricardo P.B., Pedro T., João P.D., Ricardo J.A.S. (2015) Lubrication aspects during single point incremental forming for steel and aluminum materials" International journal of precision engineering and manufacturing, Vol. 16, No. 3, pp. 589-595 March 2015 / 589.
[18] J. Diabb, C.A. Rodríguez, N. Mamidi, J.A. Sandoval, J. Taha-Tijerina, O. Martínez-Romero, A. Elías-Zúñiga (2017) Study of lubrication and wear in single point incremental sheet forming (SPIF) process using vegetable oil nano lubricants. Wear 376-377 (2017) 777–785.
[19] J. Kishore, J.F. Duarte, A.Reis, M.B. Silva (2017) Microstructural investigation and lubrication study for single point incremental forming of copper. International Journal of Solids and Structures (2017) 1–7.