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Optimization and Prediction of Process Parameters in SPIF that Affecting on Surface Quality Using Simulated Annealing Algorithm

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Abstract

Incremental sheet metal forming is a modern technique of sheet metal forming in which a uniform sheet is locally deformed during the progressive action of a forming tool. The tool movement is governed by a CNC milling machine. The tool locally deforms by this way the sheet with pure deformation stretching. In SPIF process, the research is concentrate on the development of predict models for estimate the product quality. Using simulated annealing algorithm (SAA), Surface quality in SPIF has been modeled. In the development of this predictive model, spindle speed, feed rate and step depth have been considered as model parameters. Maximum peak height (Rz) and Arithmetic mean surface roughness (Ra) are used as response parameter to assess the surface roughness of incremental forming parts along and across tool path direction. The data required has been generate, compare and evaluate to the proposed models that obtained from SPIF experiments.

Simulated Annealing Algorithm (SAA) is utilized to develop an effective mathematical model to predict optimum level. In simulated algorithm (SA), an exponential cooling schedule depending on Newtonian cooling process is used and by choosing the number of iterations at each step on the experimental work is done. The SA algorithm is used to predict the forming parameters (speed, feed and step size) on surface quality in forming process of Al 1050 based on Taguchi‘s orthogonal array of L9 and (ANOVA) analysis of variance were used to find the best factors that effect on the surface quality.

Keywords: *Simulated Annealing Algorithm (SAA), Single Point Incremental Forming (SPIF), Forming Parameters, Surface Roughness.*

1. Introduction

Incremental forming is a flexible sheet metal forming process which uses simple generic and cheaply made tools to locally deform a sheet of metal along a predefined tool path without using of dies. By using CNC milling machine, this process need to a very simple. Tool diameter, spindle speed, step depth, friction, feed rate, toolpath and wall angle are some of the important forming variables that effect on the product accuracy using this method of forming process [1]. Less geometrical accuracy and more processing time with respect to conventional processes are some of the limitations of this process; so many researchers attempted to solve this problem by using different types of analysis methods to predict and optimized the best process parameters that give good surface accuracy [2]. A schematic diagram of single point Incremental Forming (ISF) illustrated in Figure (1). [3]

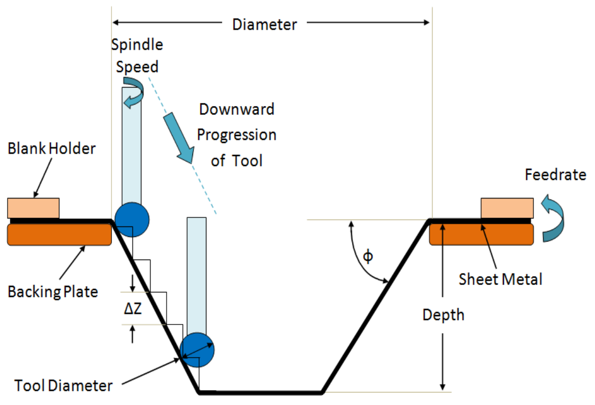

Fig. 1. Principle of the single point incremental forming process [3].

2. Literature Review

A series of experiment have been carried out in design of experiments to investigate the effect of forming parameters such as spindle speed, feed rate and step size on surface roughness using vertical CNC milling machine. R. VARTHINI and et al [4]**,** use a three-layer back propagation neural network (BPNN) and genetic algorithm (GA), a second order mathematical prediction model was established in this paper to predict and optimize both the wall angle and surface roughness for the material Al-1050 alloy sheets in relation with five common SPIF forming parameters: vertical step size, lubrication, spindle speed, tool diameter and feed rate. O.U. Lasunon [5], illustrated the effect of process parameters on the mean surface roughness (Ra) of aluminum alloy product by a single-point forming process. Three present parameters are forming depth (0.015 and 0.030 in), feed rate (12.5, 25 and 50 in/min), and wall angle (45° and 60°). M. Vahdati and et al [6], present optimization and a statistical analysis of factors that effected on this varibles are used the UVa SPIF process. at this work, the experiment design technique using response surface methodology (RSM). The specified input variables of the process used as the controllable factors, like sheet thickness, vertical step size, wall inclination angle, tool diameter and feed rate are. The results obtained from the regression analysis and analysis of variance (ANOVA) of the experimental data confirms the accuracy of the mathematical model.
The literature review illustrated in Table (1).

Table 1,
Literature review presents the optimization approach in SPIF process.

No.	Authors	Optimization Approach
1	S. Kurra and et al (2012)[2]	Artificial neural networks and Genetic Algorithm
2	H. S. Beravala and et al (2015)[3]	Feasibility Study
3	V.Mugendiran and et al (2014)[7]	Response surface methodology
4	B. S. Raju and et al (2014)[8]	Taguchi Method, ANOVA
5	S.P.Shanmuganatan and et al (2014)[9]	Response Surface Methodology
6	Er. Alamdeep C. and et al (2015)[10]	Taguchi method and Artificial Neural Networks
7	J. R. Patel and et al (2015)[11]	grey relational analysis
8	P.B.Uttarwar and et al (2015)[12]	Taguchi method
9	J. R. Patel and et al (2015)[13]	ANOVA

3. Experimental Work
3.1. Material and Process

Samples of (Al 1050) aluminum metal sheets, 225 x 225 x 0.9 mm, were used to perform the experiments (9-samples). The geometry of part is shown in Figure (2).

The experimental work was applied using oil lubricant on a C-tek three-axis (KM-80D), CNC milling machine equipped with a maximum rotational speed of 6000 rpm, feed rate of 10 m/min. CNC part programs for tool path was created. The experimental work of the workpiece for hem-spherical tool is illustrated in Figure (3). The chemical composition and mechanical properties of this Aluminum (Al 1050) is illustrated in tables (2 & 3). For forming operation the tool used for performing is tool steel (12mm diameter).

using a surf test (Mahr pocket surf test) measuring instrument, the forming surface was measured after cut off the samples to simplest the measurement procedures at three different positions with the cutoff length 2 mm and maximum peak to valley height (Rz) and Arithmetic mean surface roughness (Ra) are used as output parameters to evaluate the surface quality of incremental forming product along and across tool path direction and values are recorded in microns that illustrated in Figure (4).

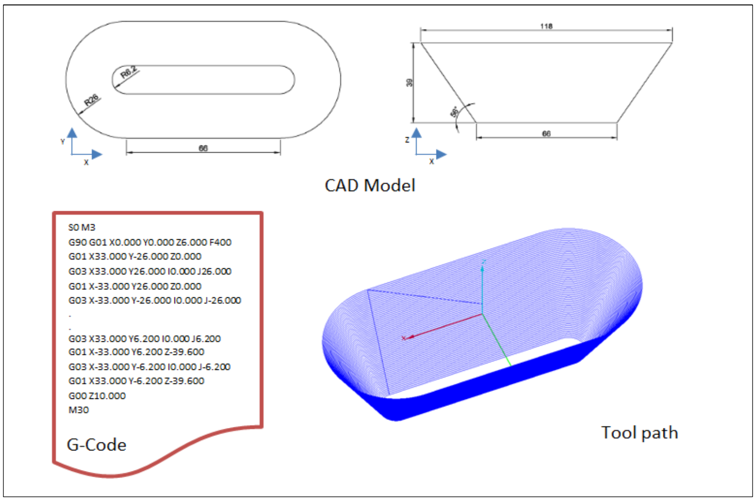

Fig. 2. Geometry of part and part program.

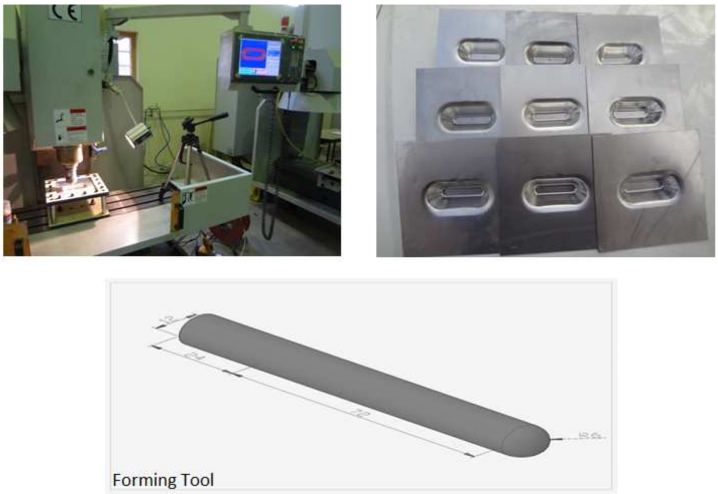

Fig. 3. The experimental setup and nine-samples

Fig. 4. Surface roughness measurement device

Table 2,
Chemical composition of Al 1050 alloy (wt %)

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ni	Zn
Percentage %	99.5	0.001	0.013	0.315	0.001	0.013	0.142	0.003	0.006

Table 3,
Mechanical properties of Al 1050 alloy.

Yield Point (MPa)	Ultimate Strength (MPa)	Hardness (HBR)	Elongation (%)
65-78	80-100	20-30	35-42

3.2. Plan of Experiments

The powerful tool for improving productivity is Taguchi method has become during research and development in recent years so at low cost that can be produced good quality parts quickly. Uses a special design of orthogonal arrays with a small number of experiments Taguchi method to study the entire parameter space. The methodology of Taguchi for three factors at three levels is used for the applied of experiments. To define the nine trial conditions, is used the degrees of freedom required for the study is six and Taguchi's (L9) orthogonal array. The levels and process parameters are illustrated in table (4). The average response and Replicated twice values for each of the nine trials or process designs are used for this work. Table (5) illustrated the present work and the test results, and figures (5, 6 and7) present the relationship between experimental data.

Table 4,
Process parameters and their levels

Parameters	Unit	Level 1	Level 2	Level 3
Rotational Speed (S)	Rev/min	0	400	800
Feed Rate (F)	mm/min	400	700	1000
Forming depth (D)	mm	0.3	0.6	0.9

Table 5,
Experimental layout using an L9 orthogonal array and corresponding results.

	Process Parameters				Average Response			
Exp. No.	Spindle speed rev/min	Feed rate mm/min	Depth Size mm	Time min	Surface roughness µm $R_{a\text{-}across}$	$R_{m\text{-}across}$	$R_{a\text{-}along}$	$R_{m\text{-}along}$
1	1	1	1	77.7	0.63	4.8	0.30	2.1
2	1	2	2	22.4	1.05	5.4	0.33	2.1
3	1	3	3	10.6	2.33	9.3	0.38	2.7
4	2	1	2	39.3	1.08	4.7	0.72	4.1
5	2	2	3	15.1	1.02	5.9	1.33	6.9
6	2	3	1	31.1	0.95	5.4	1.10	5.9
7	3	1	3	26.4	0.93	7.5	0.54	2.6
8	3	2	1	44.4	1.01	3.6	0.98	5.9
9	3	3	2	15.7	0.9	5.9	1.49	3.8

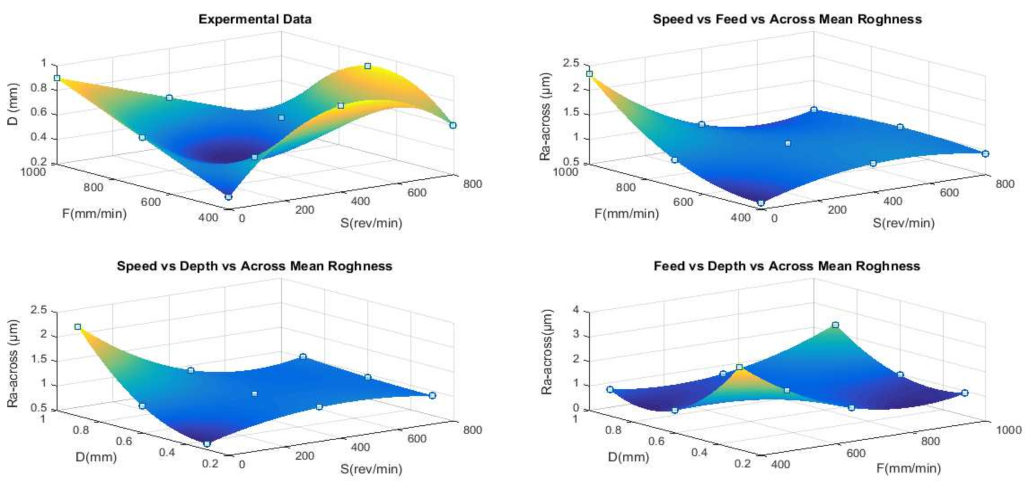

Fig. 5. The relationship of mean roughness (across) with respect to process variables.

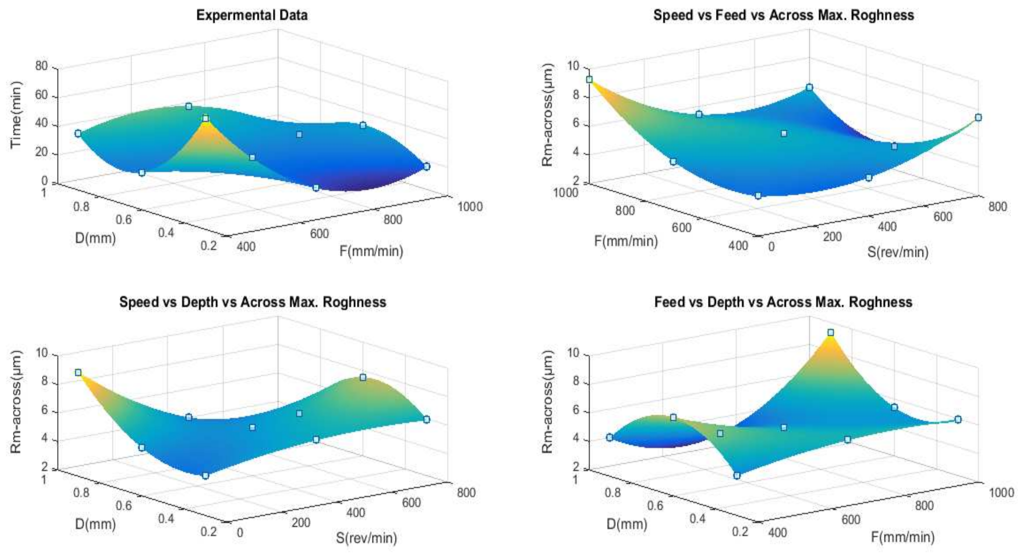

Fig. 6. The relationship of maximum roughness (across) with respect to process variables.

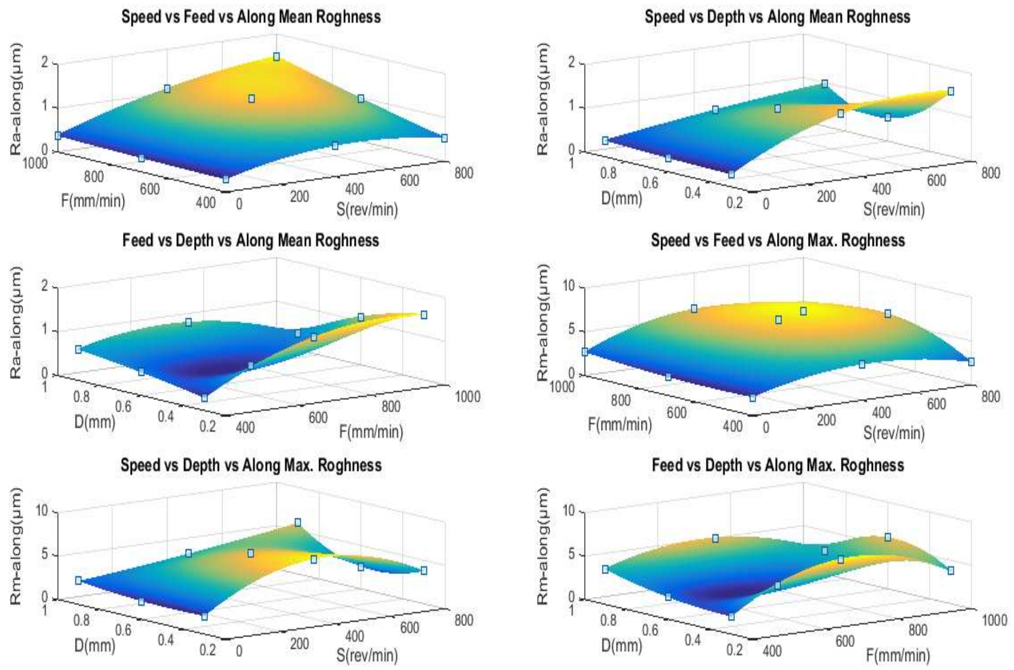

Fig. 7. The relationship of roughness (along) with respect to process variables.

4. Optimization of Machining Parameters.

4.1. Structure of Simulated Annealing Algorithm.

The steps of the present work (simulated annealing algorithm (SAA)) are shown in Figure (8).

Using simulated Annealing algorithms (SAA) to optimize the present work, the limited optimization problem is stated as follows:

From the given data for surface quality, using fitness value the response function can be found as:

Minimize,

$$Time=162.544-0.099*F-228.278*D+93.519*D^2+0.086*F*D \quad ...(1)$$

$$R_{a\text{-}across}=1.979+0.002*S-0.006*F+1.006*D-0.005*S*D+1.5D^2+4.33*10^{-6}*F^2 \quad ...(2)$$

$$R_{m\text{-}across}=10.503-0.001*S-0.019*F-4.417*D-0.001*S*D-0.001*F*D+1.486*10^{-5}*F^2+8.333*D^2 \quad ...(3)$$

$$R_{a\text{-}along}=0.062+0.002*S+0.003F-2.293*D-3.104*10^{-6}*S^2-2.481*10^{-6}*F^2+1.25*10^{-6}*S*F+0.002*S*D+0.003*F*D \quad ...(4)$$

$$R_{m\text{-}along}=-1.993+0.014*S+0.024*F-14.5*D-1.521*10^{-5}*S^2-1.593*10^{-5}*F^2+11.296*D^2 \quad ...(5)$$

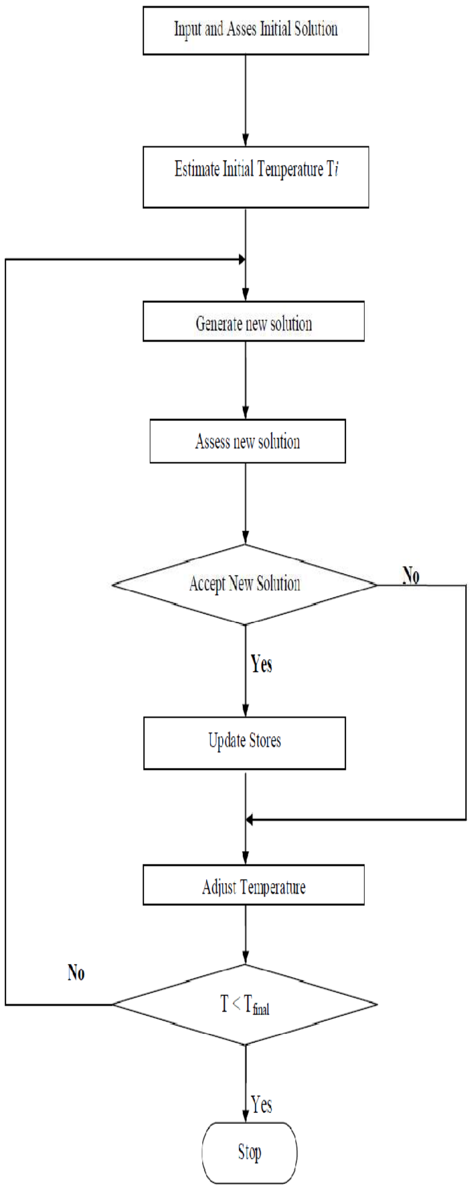

Fig. 8. Simulated Annealing Flowchart.

Subject to

0 rev/min ≤ V ≤ 800 rev/min

400 mm/min ≤ F ≤ 1000 mm/min

0.3 mm ≤ D ≤ 0.9 mm

xiu ≤ xi ≤ xil

where xiu and xil are the upper and lower bounds of process parameters xi . x1, x2, x3 are the spindle speed, feed rate and forming depth respectively. The following parameters have been selected to obtain optimal solutions with less computational effort to optimize the related work using SAA.

Initial Temperature Ti= 1 C^o

Maximum no. of iterations = 5709

4.2. Performance Evaluation of Simulation Analysis

The SA algorithm was applied using MATLAB R2014B. The input forming variables were input to the simulated program. Table (6) presents the input parameters and the minimum values of surface roughness. In order to get the minimum surface roughness, it is possible to find the variables at which the SPIF process can be used. Figures (9, 11, 13 and 15) shows the applying of SAA and figure (10, 12, 14 and16) shows Performance of SAA. From the optimization results of the SA program it can be concluded that it is possible to select a combination of spindle speed, feed and forming depth to achieve the better surface finish.

Table 6,
The input parameters with respect to output values of simulated annealing algorithms.

Forming Parameters	Simulated Annealing Algorithm			
	$R_{a\text{-}across}$	$R_{m\text{-}across}$	$R_{a\text{-}along}$	$R_{m\text{-}along}$
Rotational Speed ,S (rev/min)	2.743	796.671	201.065	0.024
Feed, F(mm/min)	696.318	637.803	401.55	400.343
Depth of Forming, D (mm)	0.3	0.303	0.899	0.636
Min. Surface Roughness, (microns)	0.3387	2.6253	0.1762	0.4096

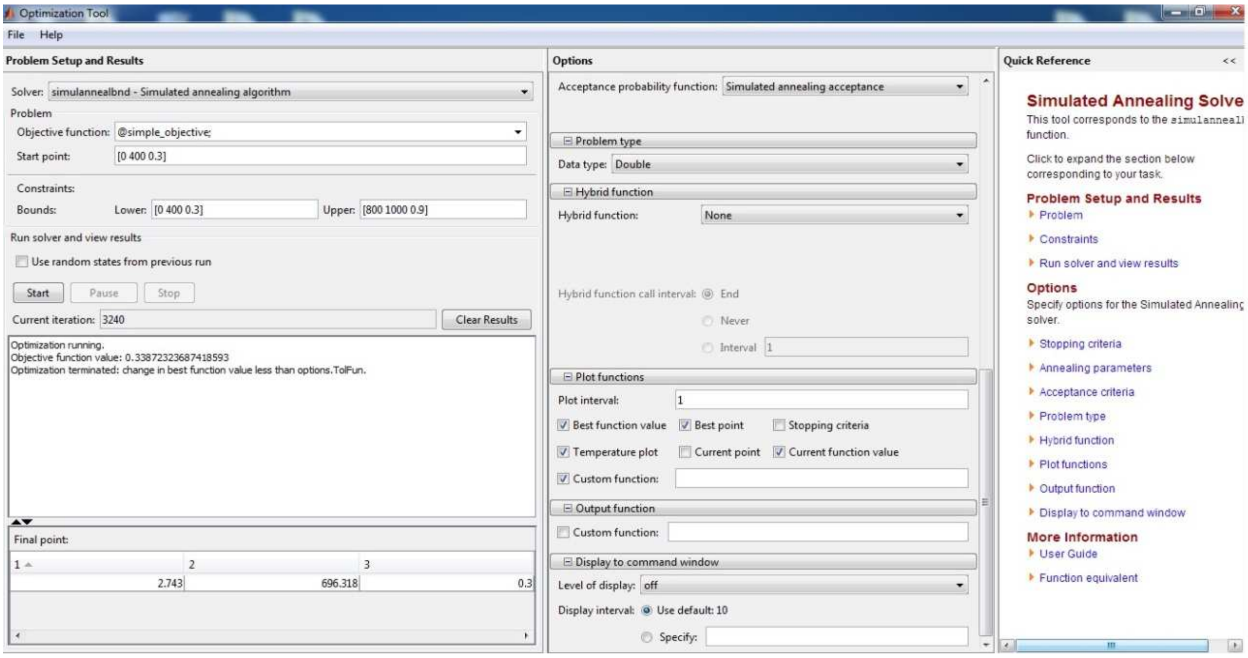

Fig. 9. Applying of Simulated Annealing Algorithm ($R_{a\text{-}across}$).

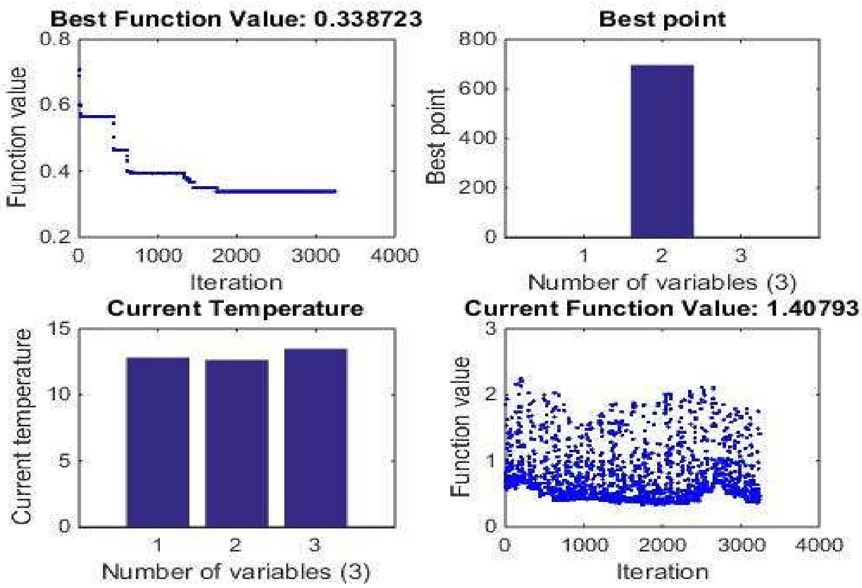

Fig. 10. Performance of Simulated Annealing Algorithm ($R_{a\text{-}across}$)

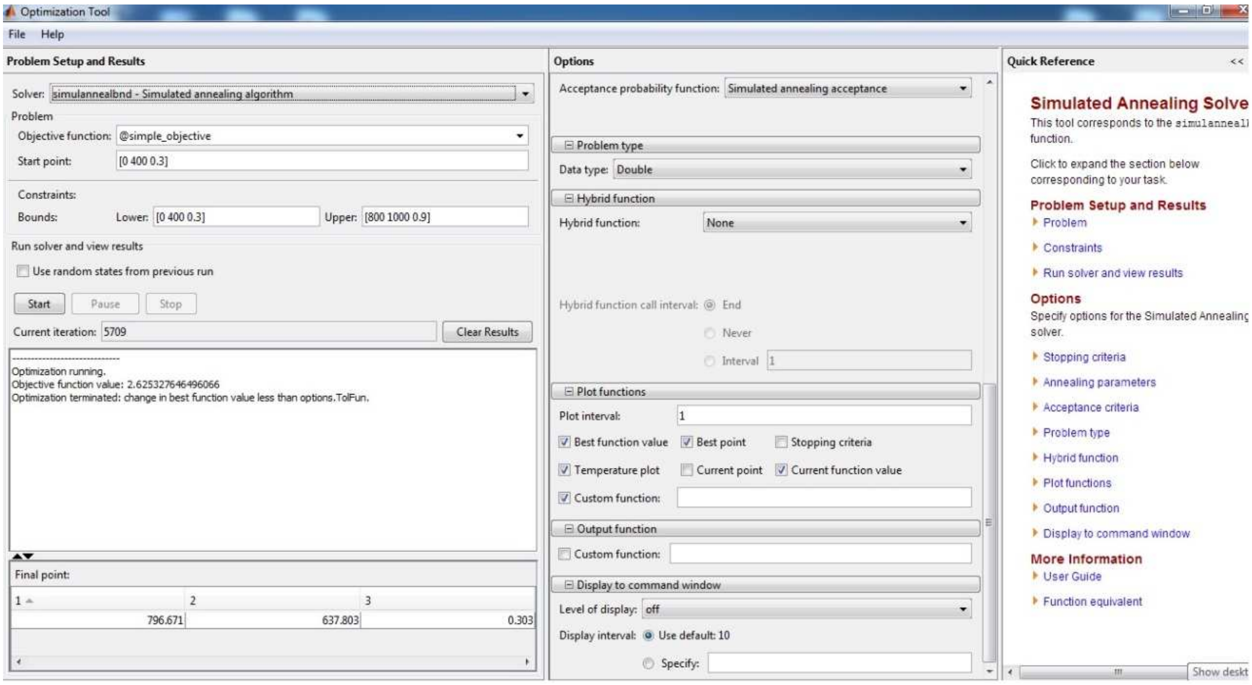

Fig. 11. Applying of Simulated Annealing Algorithm ($R_{m\text{-}across}$).

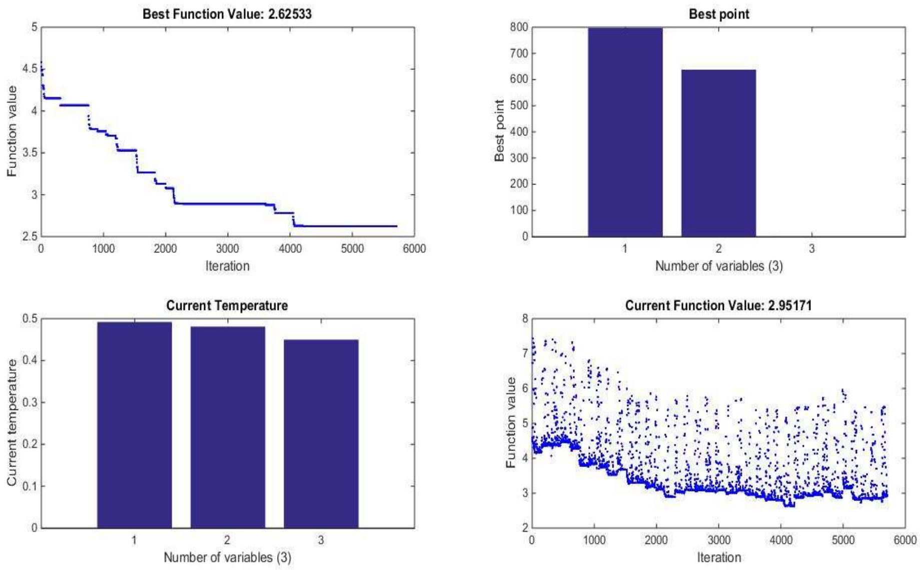

Fig.12. Performance of Simulated Annealing Algorithm ($R_{m\text{-}across}$)

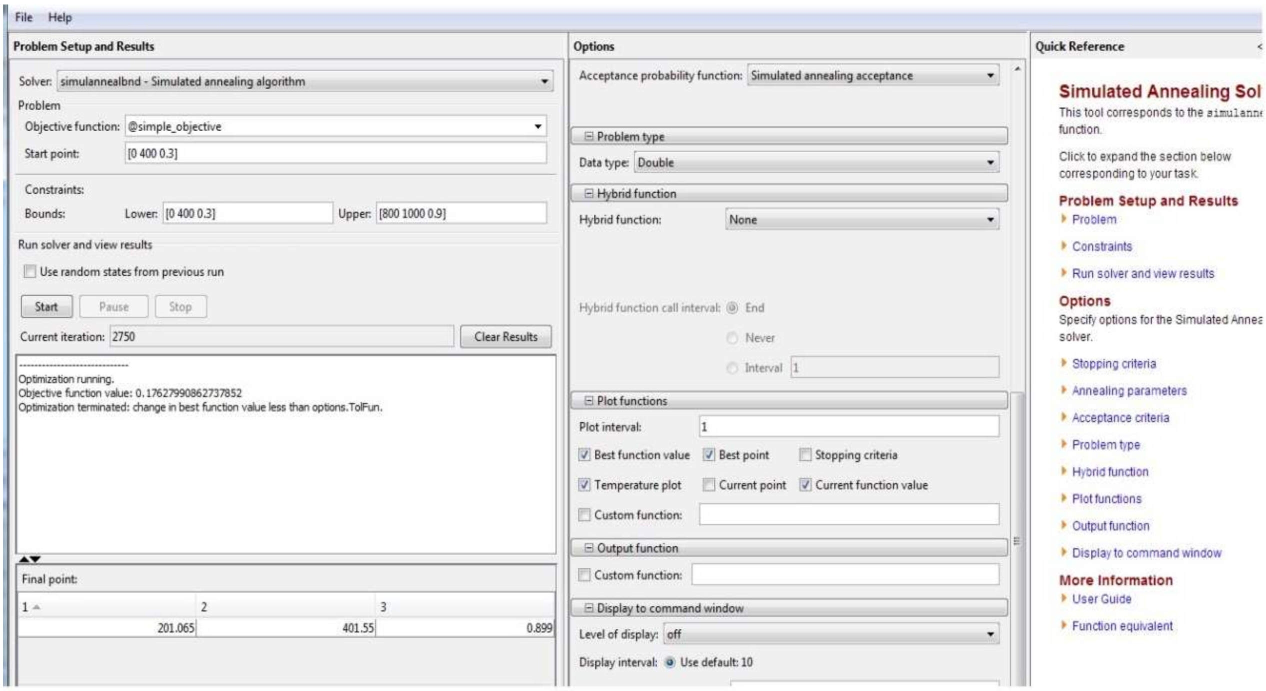

Fig. 13. Applying of Simulated Annealing Algorithm ($R_{a\text{-}along}$).

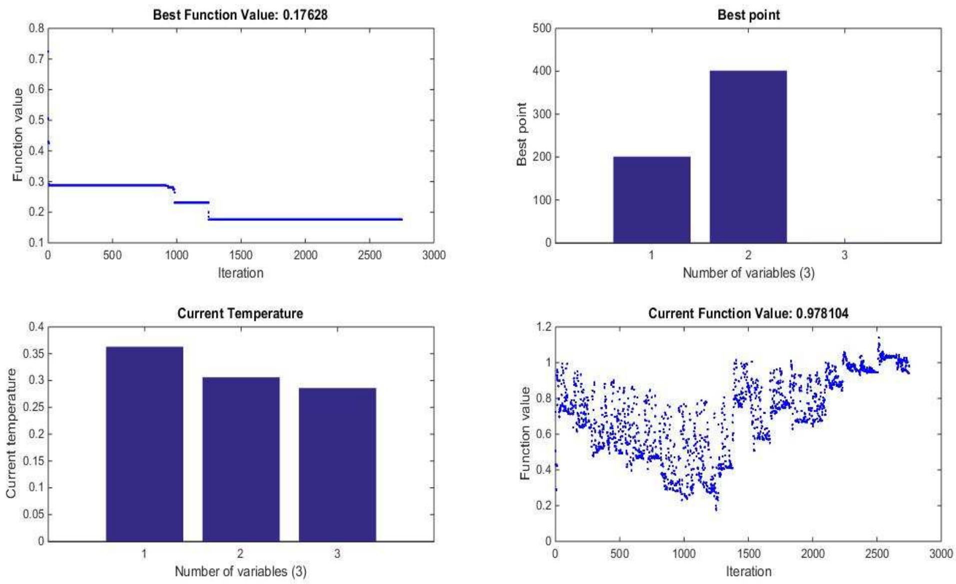

Fig. 14. Performance of Simulated Annealing Algorithm ($R_{a\text{-}along}$).

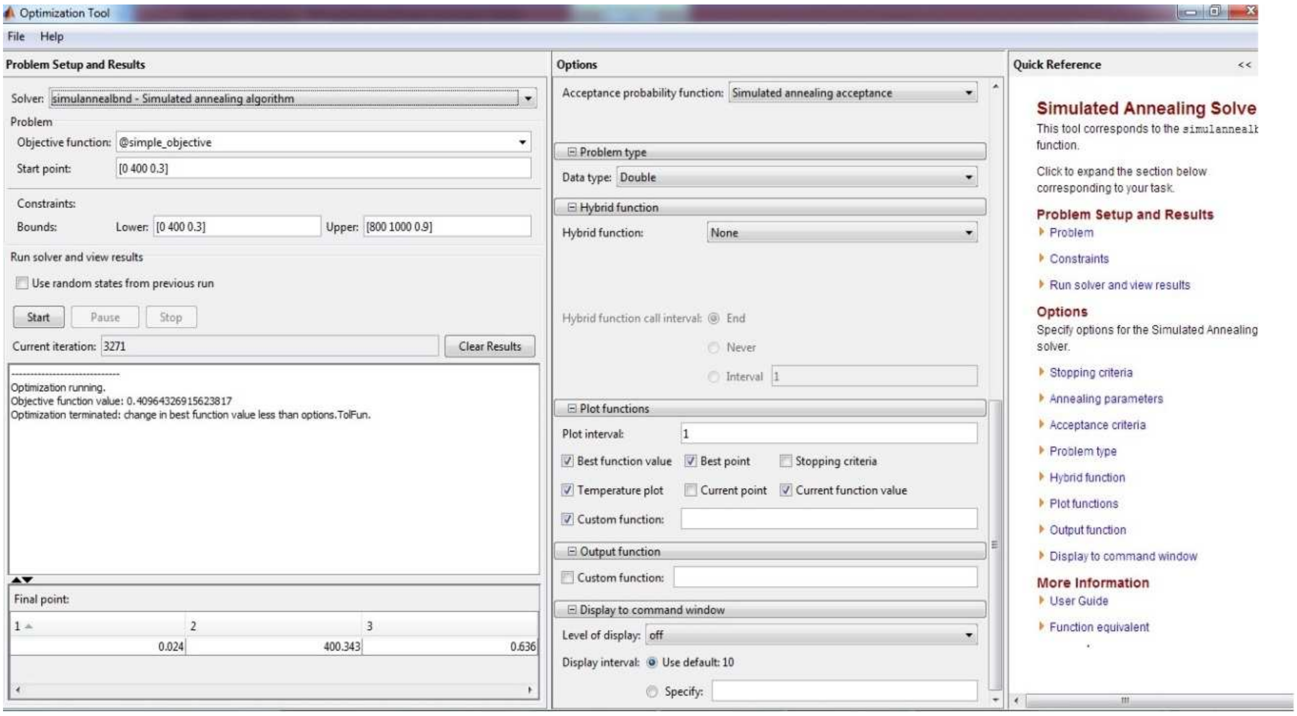

Fig. 15. Applying of Simulated Annealing Algorithm ($R_{m\text{-along}}$).

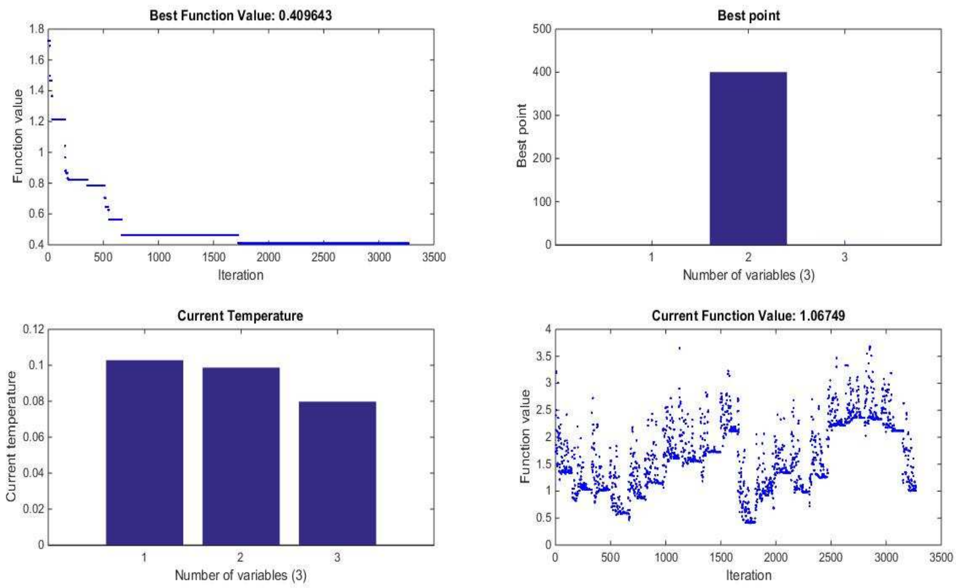

Fig. 16. Performance of Simulated Annealing Algorithm ($R_{m\text{-along}}$).

5. Conclusion

1. In incremental forming process, the process parameters (speed, feed and step size) is the main factors that effect on surface quality.
2. Rotational speed in incremental forming process have a little effect on process time and may be neglected in this study, while feed rate and step size have the main effect on process time (99%).
3. The results of Simulated Annealing Algorithm and the effectiveness experiments confirm that the developed empirical models for the output responses provide the predicted values and shows an excellent fit of these response factors that are close to the experimental values , at (92-98.8)% confidence level. But out of the optimization range, the predicted was decrease to 82% especially at high range of feed and

forming depth due to forming force and vibration due to high force.

4. Surface roughness has been test across the direction of tool path take the main effect on surface quality and the surface roughness along the tool path direction have a little effect but must be taken.
5. Low rotational speed gave the best surface quality, because decrease the average across roughness, the effectiveness range up to (70%).
6. High feed rate take the best surface quality up to (28%) in both directions of testing.
7. Decrease in step size gave the best surface quality up to (51%), in another wise increase in process time.

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الامثلية والتنبوء لمتغيرات عملية التشكيل النقطي التي تؤثر على جودة السطح الناتج باستخدام خوارزمية محاكاة التلدين

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الخلاصــة

تعد عملية التشكيل التزايدي من التقنيات الحديثة في تشكيل الصفائح المعدنية التي تتم عن طريق سلسلة من الحركات الدورانية التي تؤديها عدة التشكيل في نقطة تشكيل واحدة وبشكل متسلسل. وتتم حركة هذه العدة من قبل ماكنة التشغيل المبرمج. بهذه العملية الأداة تشكل الصفائح بصورة آنية من خلال عملية السحب النقي. هذا البحث يقوم بالتركيز على تطوير نموذج لتنبوء جودة السطح الناتج من عملية التشكيل النقطي. تتم عملية التطوير الحاصلة لنموذج التنبوء باستخدام متغيرات العملية (سرعة دوران، معدل التغذية وعمق النزول) التي اخذت بنظر الاعتبار في عملية بناء النموذج. تم اخذ قيم متوسط الخشونة والخشونة العظمى استجابة لمتغيرات العملية وباتجاه مسار العدة وبصورة عامودية على مسار العدة. حيث ان مجموع هذه البيانات تم توليدها، ومقارنتها وتقويمها بين النموذج المقترح والقيم الناتجة من الجانب العملي لعملية التشكيل النقطي.

تم استخدام خوارزمية التلدين لتطوير النموذج الرياضي الفعال للتنبؤ بالمستوى الأمثل للعملية. في هذه المحاكاة، يتم عمل جدول التخفيض الأسي على أساس عملية تخفيض نيوتن ويتم اجراء التجارب الاختيارية على عدد من التكرارات في كل خطوة. نفذت خوارزمية التلدين على متغيرات عملية التشكيل النقطي (السرعة، التغذية وعمق النزول) وتاثيرها على دقة السطح الناتج في عملية تشكيل صفائح الالمنيوم (١٠٥٠) على أساس متعامدات تاكوشي وبمستوى (L9) وتحليل التباين (ANOVA) للتعرف على أهمية هذه العوامل و تاثيرها على جودة السطح.