# Modeling and Optimization of Machine Parameters Using Simulated Annealing Algorithm (SAA)

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**Received on:7/1/2016 & Accepted on:19/5/2016**

## ABSTRACT:

The present work deals with the mathematical modeling and analysis of machining response such as the surface roughness in the milling of aluminum alloy (AA6061). There are several machining variables like rotational speed, depth of cut and feed rate used to find the quality of surface quality.

Simulated Annealing Algorithm (SAA) is utilized to develop an effective mathematical model to predict optimum level. In simulated annealing algorithm (SAA), an exponential cooling program depending on Newtonian cooling is applied and experimentation is done on choosing the number of iterations for each step. The SAA is used to predict the cutting variables (rotational speed, feed rate and depth of cut) on product quality in dry milling of Al 6061 based on Taguchi's orthogonal array of L9 and analysis of variance (ANOVA) were apply to determination the important factors that effect on surface quality.

At last, tests were conducted to confirm by making a comparison between the experimental results and the model developed. The experimental results have shown the performance of machining in the milling can be improved effectively using this algorithm.

**Keywords:** Simulated Annealing Algorithm (SAA), CNC milling machine, machining parameters, Surface roughness.

## INTRODUCTION:

Increasing the productivity and decreasing the surface roughness of the product parts are the main parameters of metal-based. These increased of productivity in observe the aspects of the milling process. Goodness of milling process can be judged by product quality [1]. The improvement of surface roughness will be improved the quality.

Rotational speed, feed rate and depth of cut are the variables that can be adjusted in milling process. Most of the operators use trial and error method to find the suitable cutting parameters. In machining process, the optimal cutting conditions are not the good way. So the aim of this work is to find the best variables (rotational speed, feed rate, and cutting depth) so that product quality is



https://doi.org/10.30684/etj.34.7A.18
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optimized. Aluminum has much application in industries. Also train companies and automotive aircraft need to replace cast iron and steel with lighter metal like aluminum. So it is significant to know the machining action of aluminum.
There are several optimization methods such as simulated annealing algorithm, genetic algorithm, neural network, taguchi technique etc. to find out optimum cutting variables. SAA is best method to define and also easy to perform.

## 2. Literature survey

A number of experiments have been carried out in design of Experiments to investigate the effect of milling variables like rotational speed, feed rate and cutting depth on surface quality in vertical milling machine. **Bharat S. Patel and et al (2012),** study the optimum machining parameters that effect on surface quality. It used the taguchi methods to optimize the surface quality in milling of aluminum. Taguchi's technique is a best tool to optimization, which offers effective approach and a simple to optimize the system performance. **Najiha M.S. and et al (2013),** use the end milling process of AA6061T6 with wet cooling conditions to determine the optimum operating parameters. The result model is tested for optimization using genetic approach. **V. Devkumar and et al (2015),** present work deals with the mathematical modeling and analysis of machining response such as the surface roughness and tool wear in the turning of aluminum alloy 6061. The methodology of response surface is utilized to develop the effective mathematical model to predict optimum level. **Rizwan Anwar and et al (2015),** focused on identifying the optimum values of input parameters to achieve better surface finish. A series of experiments have been performed using Aluminum Alloy 7075-T 7351, as this material is used in various applications. Central Composite Design (CCD) technique in the Design Expert has been applied to carry out the analysis of experimented results. The list of literature review has been illustrated in Table (1).

Table (1) Review of the literature focusing on the optimal approach in the machining process

| No. | Authors | Optimization Approach |
|---|---|---|
| 1 | Milon D. Selvam and et al (2012) | Genetic Algorithm |
| 2 | J.Pradeep Kumar and et al (2012) | Taguchi method |
| 3 | WDS.MILTON.PONNALA (2012) | Non-dominated Sorting Genetic Algorithm |
| 4 | K. Divya Theja and et al (2013) | Artificial Neural Networks (ANN) |
| 5 | Lohithaksha M Maiyar and et al (2013) | Grey-Taguchi method |
| 6 | Singh G. and et al (2014) | Response surface methodology (RSM) |
| 7 | Vishal Parashar and et al (2014) | Taguchi method |
| 8 | Sarang S. Kulkarni and et al (2014) | Taguchi method |
| 9 | Sony Thomas and et al (2015) | Grey-Taguchi method |

## 3. Experimental work:

### 3.1. Material and process:

The experimental work was achieved in dry cutting conditions on a C-tek three-axis (KM-80D), CNC vertical milling machine with the maximum rotational speed of 6000 r.p.m and 10 m/min in feed rate[14]. The CNC programs generated using Matlab package. The material used of workpiece was Aluminum (Al 6061) in cylinder shape with 40mm diameter and 30mm (length)- 20mm (width)-15mm (height) pocket. Setup of The experimental work using ball end mill is illustrated in figure (1). The chemical composition of this Aluminum (Al 6061) alloy is illustrated in table (2), while the mechanical properties present in table (3). The tool material applied for achieved the experimental work is high speed steel (HSS) (8mm diameter, 3-flutes). Tools with three teeth are selected for best surface finish and material remove rate.

The product surface was tested using a surf test at three positions (Mahr pocket surf test) using cutoff length 4 mm and the average surface roughness (Ra) is recorded in microns that illustrated in figure (2).

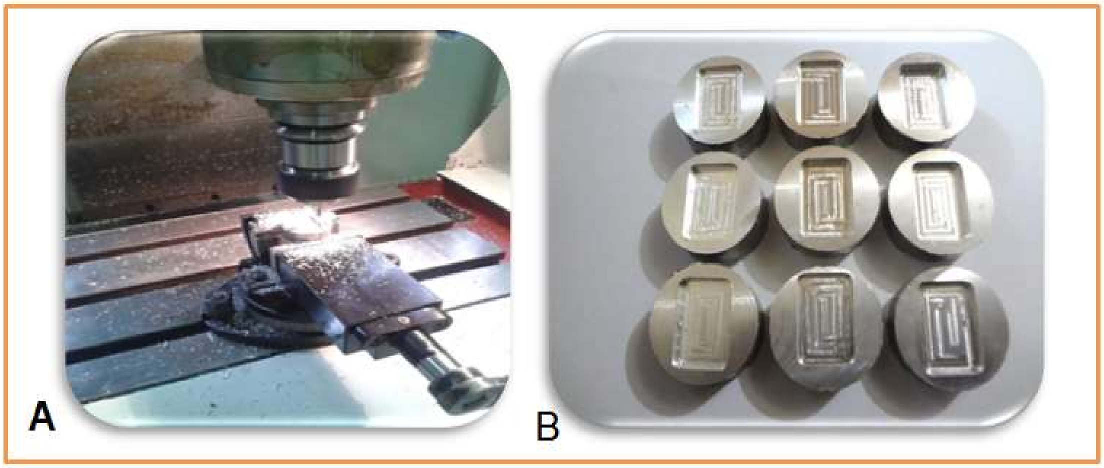


**Figure (1) (a) Experimental work applied in university of technology (b) nine-actual workpiece machined at proposal work.**

**Figure (2) surface roughness test**

**Table (2) Chemical composition of Al 6061**

| Elements | Al | Cr | Cu | Fe | Mg | Mn | Si | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Percentage wt % | 95.8-98.6 | 0.04-0.35 | 0.15-0.4 | Max 0.7 | 0.8-1.2 | Max 0.15 | 0.-0.8 | Max 0.15 | Max 0.25 |

**Table (3) Mechanical properties of Al 6061 alloy**

| Ultimate Strength | Yield Point (MPa) | Elongation (%) | Hardness (HBR) |
|---|---|---|---|

| (MPa) | | | |
|---|---|---|---|
| 110-152 | 65-110 | 14-16 | 30-33 |

**3.2. Experiment of proposal work**

The Taguchi technique in last years is a strong tool for increase productivity through development and research so that good parts can be manufacture fast and at minimum cost. This way by using a special design of orthogonal arrays to study a small number of experiments with the entire parameter space. The Taguchi method is used for three factors at three levels and the plan for the implementation of experiments. This study needs to apply at six degrees of freedom and use Taguchi's L9 orthogonal array at (9)trial conditions. Table (4) presents the process variables and their levels. While table (5) present the experimental output and conforming average test results, and figure (3) present the relationship between experimental data.

**Table (4) process parameters and their levels**

| Parameters | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| **Spindle speed (S)** | Rev/min | 500 | 600 | 700 |
| **Feed Rate (F)** | mm/rev | 0.15 | 0.2 | 0.25 |
| **Depth Size (D)** | mm | 2 | 3 | 4 |

**Table (5) Experimental layout using an L9 orthogonal array and corresponding results**

| Expe. No. | Process Parameters | | | Average Response Values |
|---|---|---|---|---|
| | Level of Spindle speed rev/min | Level of Feed rate mm/rev | Level of Depth of cut mm | Surface roughness (Ra)μm |
| **1** | 1 | 1 | 1 | 3.38 |
| **2** | 1 | 2 | 2 | 1.67 |
| **3** | 1 | 3 | 3 | 2.6 |
| **4** | 2 | 1 | 3 | 1.51 |
| **5** | 2 | 2 | 1 | 1.71 |
| **6** | 2 | 3 | 2 | 1.84 |
| **7** | 3 | 1 | 2 | 1.5 |
| **8** | 3 | 2 | 3 | 1.81 |
| **9** | 3 | 3 | 1 | 2.33 |

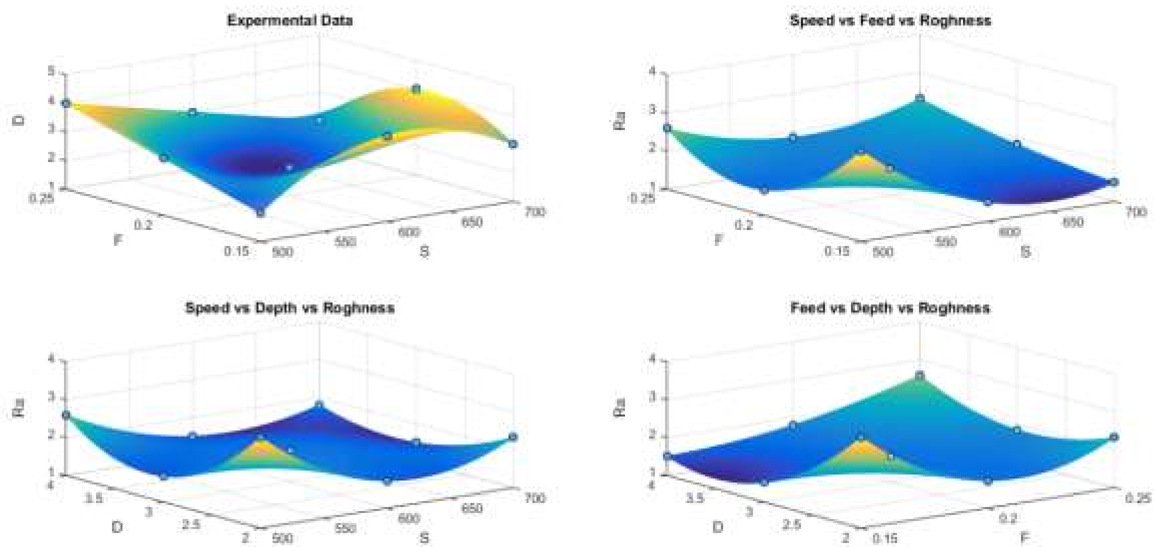


**Figure (3) Relationship between process parameters**

## 4. Optimization of machining parameters

### 4.1. Structure of Simulated Annealing Algorithm:

The construction of the present work (simulated annealing method (SAA)) is illustrated in figure (4). [15]

Stage-1: Select a first point (x), number of iterations to be accomplished at a particular temperature T; $(T = 1 \rightarrow m)$

Stage-2: Evaluate the function F= $f(x)$

Step-3: Find the next point $X_{i(T+1)} = X_{i(T)} + \lambda_i (X_{imax} - X_{imin})$ …(1)

$$\lambda_i \in (-1,1)$$

Set the new point $X_{new} = x + \Delta x$ …(2)

Stage-4: find the next value of the present function using fitness term.

$$F_{new} = f(X_{new})$$

Stage-5: find the maximum and minimum move approval parameter$\Delta F$, Set $X \rightarrow X$ new and $F \rightarrow F$ new, with, $h(\Delta F, K)$

$$h(\Delta F, K) = \frac{1}{1+\exp(\Delta F/K)} \quad \ldots(3)$$

K= Current temperature, $\Delta F =$ F new – F

Stage-6: go to the next value T, if T equal to the maximum stop; otherwise go to STEP-3

Stage-7: Reduce the value of K. $\alpha =$ cooling rate, $(\alpha = 0 \rightarrow 1)$[16]:

$$\left(\frac{\min K}{K_o}\right)^{1/\max \text{no.of iteration}} \quad \ldots(4)$$

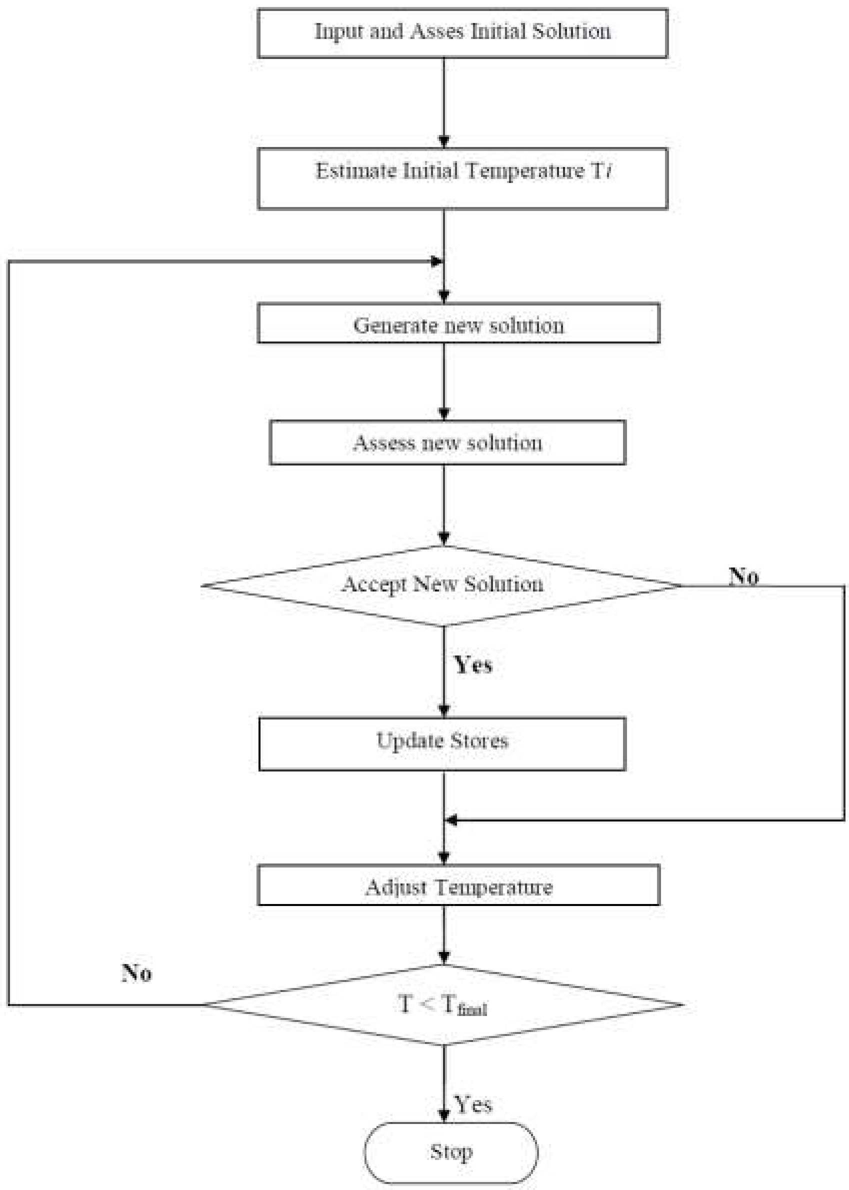


**Figure (4) Simulated Annealing Flowchart**

In order to minimize the present problem (surface roughness) using simulated Annealing (SA), the constrained optimization problem is begun as follows:
The data of surface quality that observed from the present work, the response function has been Identified using suitability function as shown in table (6), defined as
Minimize,
$Ra=30.2933-0.019833*S-212.5667*F-1.1483*D+75.333*F^2+0.075*D^2+0.191333*S*F-0.0055*S*D+21.1333*F*D$

Subject to
500 rev/min ≤ Speed ≤ 700 rev/min
0.15 mm/rev ≤ Feed ≤ 0.25 mm/rev
2 mm ≤ Depth ≤ 4 mm
And by applying the above range of process parameters in simulated algorithm to find the optimum condition in milling process using the conditions:
Initial Temperature Ti= 1 $C^o$
(Initial Temperature refers to the corresponding field of the options structure)
Maximum no. of iterations = 1520

**Table (6) the response function and their coefficients**

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 30.293 | .000 | | . | . |
| | s | -.020- | .000 | -2.757- | . | . |
| | f | -212.567- | .000 | -14.776- | . | . |
| | d | -1.148- | .000 | -1.596- | . | . |
| | ff | 75.333 | .000 | 2.100 | . | . |
| | dd | .075 | .000 | .628 | . | . |
| | sf | .191 | .000 | 9.652 | . | . |
| | sd | -.006- | .000 | -5.167- | . | . |
| | fd | 21.133 | .000 | 7.442 | . | . |

a. Dependent Variable: r

### 4.2. Simulation Work and effective Estimate

The Simulated method was developed in MATLAB. The process variables range were input to the SAA technique. Table (7) illustrated the minimum term of product quality according to process variables SAA. to minimized surface roughness by find the conditions at which the machining process has to be executed. Figure (5) illustrated the applying of proposed work and Figure (6) illustrated Performance of this work. Hence, it can be concluded the best surface finish by minimization results of the SAA that it is select a combination of rotational speed, feed rate and cutting depth.

**Table (7) Output parameters of simulated annealing algorithms according to input variables.**

| Machining Variables | Method (SAA) |
|---|---|
| Rotational Speed ,S (rev/min) | 562.188 |
| Feed, F(mm/rev) | 0.247 |
| Depth of Cut, D (mm) | 2 |
| Min. Surface Roughness, Ra (microns) | 0.073548 |

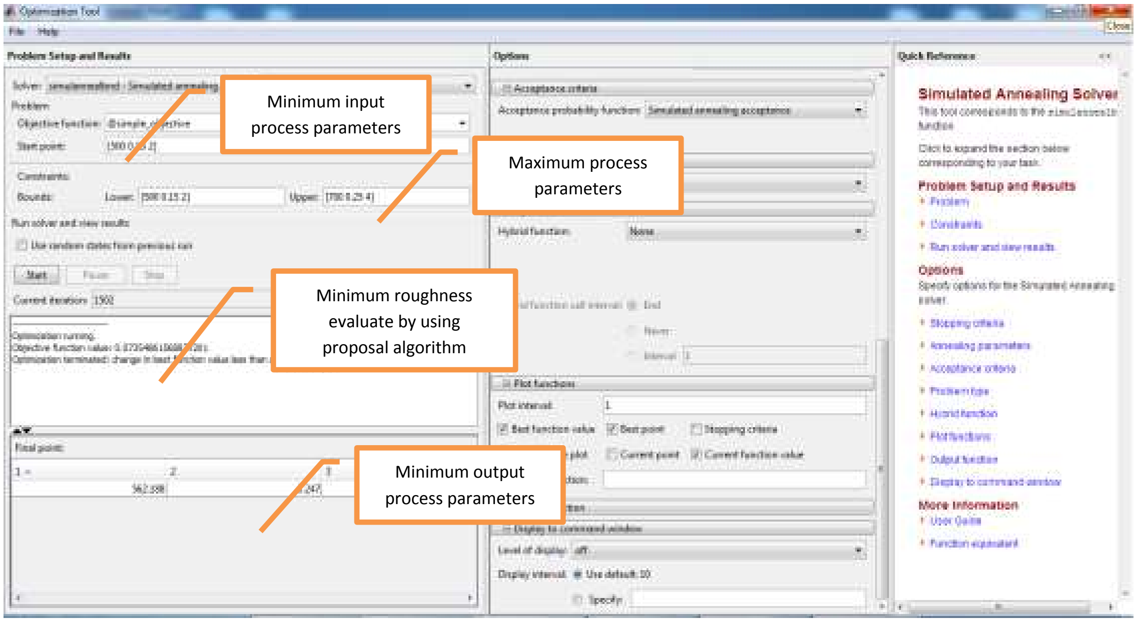


**Figure (5) Applying of Simulated Annealing Algorithm (SAA)**

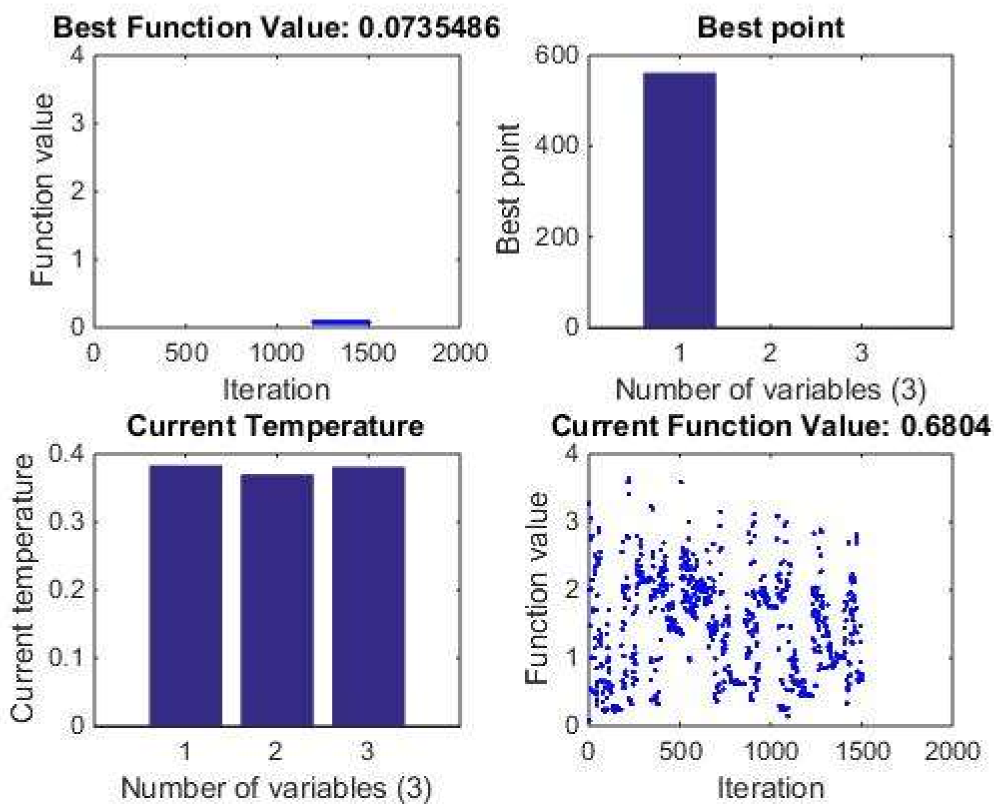


**Figure (6) Performance of Simulated Annealing Algorithm (SAA) that presents the best value of process parameters that gave minimum roughness and number of iteration.**

## CONCLUSION:

It has been established that Simulated Annealing Algorithm is an effective optimization tool for machining of Al 6061 alloy in milling process. The optimal milling variables for the machining process lies at rotational speed(S) 562.188rev/min, 0.247mm/rev for feed rate (F) and 2 mm for cutting depth (D). Further it has been found that there is a 0.073548 micron surface roughness.

The quadratic modes developed using response function within the limits of the factors investigated that accurate and can be used for prediction; the second order quadratic model was used to predict surface roughness values for experimental value by Simulated Annealing Algorithm. A comparison study is made for tabulated values and experimental values for surface roughness by using analysis of variance the model is statistically fit found on 97.25% confidence level.

The aim for this work is applying the simulated algorithm for optimizing multi response parameters with multiple factors. Analysis of the different gives that the rotational speed is the most important milling variables pursue by feed rate that effect with the multiple performance properties.

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