

# Seminar Nasional Tahunan Teknik Mesin (SNTTM) VIII

Universitas Diponegoro, Semarang 11-12 Agustus 2009

## M1-018 Implementation of Genetic Algorithm in Tool Life Optimization when End Milling of Ti64 using TiAlN Coated Tools

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### ABSTRACT

*The present works was initiated to explore the optimum tool performance in machining of Ti-64 using TiAlN coated tools end mills under wet conditions. The use of Response Surface Methodology (RSM) and Genetic Algorithm (GA) was compared in finding optimum machining conditions. It was proven that GA delivers better result than RSM, when compared using experimental trials, which was conducted according to design of experimental.*

**Keywords:** *Optimum Tool Life Performance, TiAlN, Titanium Alloys, RSM, GA.*

### 1. Introduction

Progress in Materials Science and Technology yields new applications for new materials year by year. Advanced and new materials are used as workpiece and tool material. Titanium based alloys are frequently used for low and high pressure compressors of stationary gas turbines and aircraft engines prior to its high strength to weight ratio, operating temperature up to 350 °C, low thermal conductivity and its resistance to corrosion. The Ti-6Al-4V alloy corresponds to these requirements and has a mixed structure  $\alpha/\beta$ :  $\alpha$  (hexagonal closed packed) hard, brittle with strong hardening tendency, and  $\beta$  (body centered cubic) ductile, easily formed with strong tendency to adhere [1]. Thus these properties make Ti-alloys the most attractive metallic materials for metal working, aeronautic industry, chemical industry etc [2]. Previous researcher [3]and [4] have shown that titanium alloys are considered as the difficult to machine materials, regardless of the cutting materials used.

Regarding this situation, [5] has reported the optimum cutting conditions using RSM and resulted in best tool performer in machining of Ti64. Other observations were carried out by [6] and [7]using genetic

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algorithm for machining process. None of them used this algorithm for searching the optimum cutting conditions on titanium alloys. To fill the lack of information in this field, this study was conducted by employing genetic algorithm in finding the optimum cutting conditions in term of tool life.

## 2. Experimental Set-Up

The tests were carried out with a constant  $a_a$  (axial depth of cut) 5 mm and  $a_e$  (radial depth of cut) 2 mm under flood conditions with 6% concentration of water base coolant using MAHO 700S CNC machining center for side milling operation. The grade K-30 solid carbide end mills cutter, with PVD TiAlN coated which were prepared with different radial rake angle according to DOE, were used for experimentation [5].

The reference workpiece material was a rectangular bar (110x110x270 mm) of Ti-6Al-4V. Tool life criteria used were  $VB_{max} \geq 0.25$  mm, chipping  $\geq 0.20$  mm and catastrophic failure [5].

Tool wear was measured using a Nikon tool makers' microscope with 30x magnification. The measurements of tool wear according to ISO 8688-2 were carried out for each cutting edge at initial cut and continuously after a particular length of cut (depend on wear progressive of each tool) until the end of tool life was achieved.

The independent variables such as cutting speed, feed rate, and radial rake coded with the following equation by taking into consideration the capacity and limiting cutting conditions of milling machine.

$$x = \frac{\ln x_n - \ln x_{n0}}{\ln x_{n1} - \ln x_{n0}} \quad (1)$$

Where  $x$  is the coded variable of any factor corresponding to its natural  $x_n$ ,  $x_{n1}$  is the natural value at the +1 level and  $x_{n0}$  is the natural value of the factor corresponding to the base or zero level. The level of independent variables and coding identification are illustrated in Table 1.

Table 1: Level of independent variables for end milling Ti6Al4V

Independent Variables	Level in coded form				
	$-\alpha$	-1	0	+1	$+\alpha$
$V(\text{mm.min}^{-1}) x_1$	124.53	130	144.22	160	167.03
$f_z(\text{mm.tooth}^{-1}) x_2$	0.025	0.03	0.046	0.07	0.083
$\gamma_0(^{\circ}) x_3$	6.2	7.0	9.5	13.0	14.8

## 3. Research Methodology

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The mathematical models which were built by RSM will be used to find the optimum cutting condition using GA. The results delivered using GA, are then compared to the RSM-results. The mathematical models can be described as 3F1 and 2<sup>nd</sup> CCD model.

The 3F1 mathematical model can be illustrated:

$$\hat{y} = 1.3332 - 0.3643x_1 - 1.5032x_2 + 0.2002x_3 + 0.0764x_2x_3 \quad (2)$$

with the following ranges of cutting speed  $V_c$ , feed per tooth  $f_z$  and radial rake angle  $\gamma_o$  :  $130 \leq V_c \leq 160$  m.min<sup>-1</sup>;  $0.03 \leq f_z \leq 0.007$  mm.tooth<sup>-1</sup> ; and  $7 \leq \gamma_o \leq 13$  (°) respectively.

While the 2<sup>nd</sup> CCD mathematical model illustrated as follow:

$$\hat{y} = 1.6383 - 0.3878x_1 - 1.4887x_2 + 0.1891x_3 + 0.07637x_2x_3 + 0.10684x_1^2 - 0.5451x_2^2 + 0.1327x_3^2 \quad (3)$$

with the following ranges of cutting speed  $V_c$ , feed per tooth  $f_z$  and radial rake angle  $\gamma_o$  :  $124.53 \leq V_c \leq 167.03$  m.min<sup>-1</sup>;  $0.025 \leq f_z \leq 0.083$  mm.tooth<sup>-1</sup>; and  $6.2 \leq \gamma_o \leq 14.8$  (°).

Genetic Algorithm (GA) form as class of adaptive heuristics base on principles derived from the dynamic of natural population genetic. The searching process simulates the natural evolution biological creatures and turns out to be an intelligent exploitation of a random search.

The problem to solve using genetic algorithm is coded to binary numbers known as chromosome contains the information of a set of possible process parameters. The population of chromosomes is formed randomly. The fitness of each chromosome is then evaluate using an objective function after the chromosome has been decoded. Selected individuals are then reproduced, the selecting usually in pairs through the application of genetic operator. This operator are applied to pairs of individuals with a given probability, and result in new offspring. The offspring from reproduction are then further perturbed by mutation. These new individuals then make up the next generation. These process of selection, reproduction and evaluation are repeated until some termination criteria are satisfied. The representing of genetic algorithm methodology is illustrated in figure 1.

In order to optimize the present problem using GA, the following parameters such as population size, maximum number of generation, total string length, crossover probability, mutation probability, and elitism probability have to selected to obtain optimal solution with less computational efforts.

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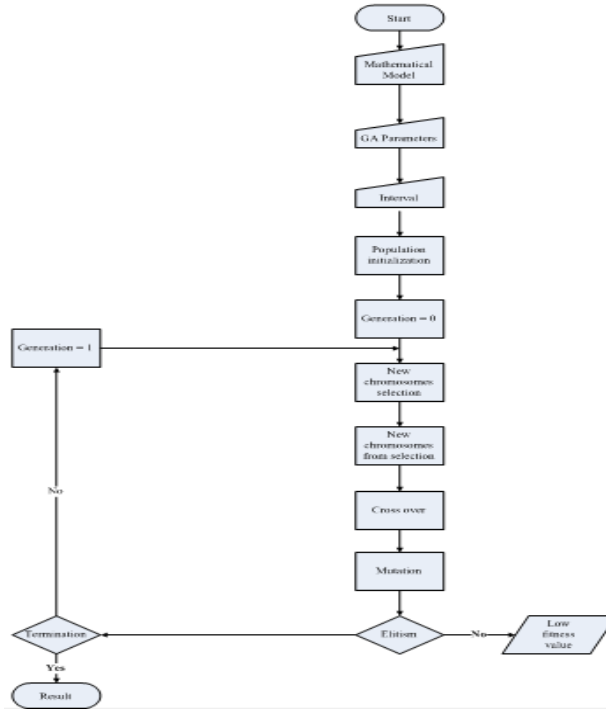


Figure 1: Flow chart of GA methodology approach

## 4. Results and Discussion

Tool life result for TiAlN coated carbide tools can be illustrated in Table 2. This result used for validating the comparison between RSM and GA.

Table 2: Tool life result for TiAlN coated carbide tools

Std. Order	Type	Cutting Speed $V$ [m/min]	Feed rate $f_z$ [mm/th]	Radial rake angle $\gamma$ ( $^\circ$ )	Tool life [min]
1	Factorial	-1	-1	-1	20.89
2	Factorial	1	-1	-1	10.91
3	Factorial	-1	1	-1	0.89
4	Factorial	1	1	-1	0.46

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Std. Order	Type	Cutting Speed $V$ [m/min]	Feed rate $f_z$ [mm/th]	Radial rake angle $\gamma$ ( $^\circ$ )	Tool life [min]
	al				
5	Factorial	-1	-1	1	29.08
6	Factorial	1	-1	1	12.81
7	Factorial	-1	1	1	1.65
8	Factorial	1	1	1	0.75
9	Center	0	0	0	5.09
10	Center	0	0	0	5.86
11	Center	0	0	0	5.26
12	Center	0	0	0	4.48
13	Axial	-1.4142	0	0	11.43
14	Axial	-1.4142	0	0	11.36
15	Axial	1.4142	0	0	3.54
16	Axial	1.4142	0	0	3.58
17	Axial	0	-1.4142	0	13.79
18	Axial	0	-1.4142	0	14.03
19	Axial	0	1.4142	0	0.21
20	Axial	0	1.4142	0	0.22
21	Axial	0	0	-1.4142	5.20
22	Axial	0	0	-1.4142	5.23
23	Axial	0	0	1.4142	8.78
24	Axial	0	0	1.4142	8.48

The optimization result of Response Surface Methodology and Genetic Algorithm shows in Table 3, and then it's compared to find out Mean Square Error (MSE) and Root Mean Square Error (RMSE) of both the method. From Table 4 can be concluded that the result was delivered by Genetic Algorithm is better than Response Surface Methodology. Its can be recognize from the value of MSE of each method.

Table 3: The Optimization result for RSM and GA

Std. Order	Experimental	RSM	GA
1	20.81	21.69106	20.95548
2	10.91	10.46776	10.87645

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3	0.89	0.92099	0.87120
4	0.46	0.44445	0.45677
5	29.08	27.78510	29.18340
6	12.81	13.40865	12.80070
7	1.65	1.60143	1.65505
8	0.75	0.77282	0.75058
9	5.09	3.79316	5.1183
10	5.86	3.79316	5.35698
11	5.26	3.79316	5.27406
12	4.48	3.79316	4.44464
13	11.43	11.02762	11.30336
14	11.36	11.02762	11.30336
15	3.54	3.682343	3.56406
16	3.58	3.682343	3.56406
17	13.79	14.20282	14.10177
18	14.03	14.20282	14.10177
19	0.21	0.210726	0.21606
20	0.22	0.210726	0.21606
21	5.20	5.135975	5.29255
22	5.23	5.135975	5.29255
23	8.78	8.76810	8.78811
24	8.48	8.76810	8.78811

Table 4: Comparison between RSM validated using experimental result

Std. Order	Experimental	RSM	GA	Estimated Error (e) RSM	Estimated Error (e) GA
1	20.81	21.691	20.955	1.324	0.021
2	10.91	10.467	10.876	0.195	0.001
3	0.89	0.9209	0.8712	9.9E-4	0.3E-4
4	0.46	0.4444	0.4567	2.4E-4	1.04E-5
5	29.08	27.785	29.183	1.676	0.010
6	12.81	13.408	12.800	0.358	8.6E-5
7	1.65	1.6014	1.6550	0.002	2.5E-5
8	0.75	0.7728	0.7505	0.5E-4	3.3E-7
9	5.09	3.7931	5.1183	1.681	0.001
10	5.86	3.7931	5.3569	4.271	0.253
11	5.26	3.7931	5.2740	2.151	1.9E-4
12	4.48	3.7931	4.4446	0.471	0.001

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Std. Order	Experimental	RSM	GA	Estimated Error (e) RSM	Estimated Error (e) GA
13	11.43	11.027	11.303	0.161	0.160
14	11.36	11.027	11.303	0.110	0.003
15	3.54	3.6823	3.5640	0.202	5.7E-4
16	3.58	3.6823	3.5640	0.010	2.5E-4
17	13.79	14.202	14.101	0.170	0.097
18	14.03	14.202	14.101	0.029	0.005
19	0.21	0.2107	0.2160	5.3E-7	3.6E-5
20	0.22	0.2107	0.2160	8.5E-5	1.5E-5
21	5.20	5.1359	5.2925	0.004	0.008
22	5.23	5.1359	5.2925	0.008	0.003
23	8.78	8.7681	8.7881	1.4E-4	6.5E-5
24	8.48	8.7681	8.7881	0.083	0.094
Mean Squared Error				0.530	0.021
Root Mean Squared Error				0.728	0.146

The representing of its comparison can be illustrated by following figure.

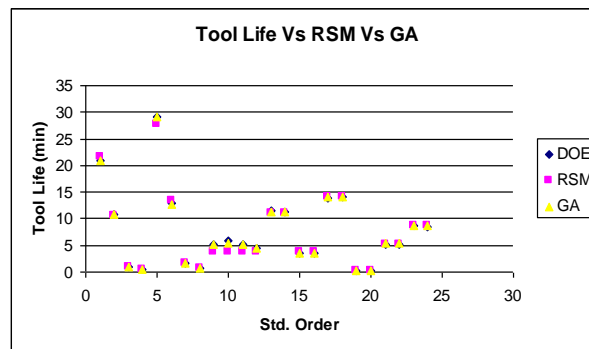


Figure 2: Comparison of both optimization method validated using experimental result

Finally it be concluded from the optimization result of Genetic Algorithm program that is possible to select a combination of cutting speed, feed rate, and radial rake angle for achieving the best possible tool life when end milling Ti-64.

## 5. Conclusions

- 1) ptimization using GA approaches the maximum value of validations data better than which using RSM. But the result using GA overshoots the maximum value of experimental data, so that for time of replacement of cutting tool, RSM delivers better prediction.

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- 2) It was found that GA can only give better results when the optimum parameters were taken in the iterations
- 3) The better overall performance in finding was delivered by GA compared to RSM. This can be recognized from the accuracy of the validation tests.
- 4) As a whole method of optimization use better GA compared to by using method of RSM.
- 5) The best results of GA was delivered using following parameters:
  - Population size : 80
  - Number of generation : 5
  - Total string length : 34
  - Crossover probability ( $P_C$ ) : 0.8
  - Mutation probability ( $P_m$ ) : 0.03
  - Elitism probability ( $P_e$ ) : 0.5

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