OPTIMIZATION OF SURFACE ROUGHNESS IN END MILLING TI-6AL-4V USING TIALN COATED TOOLS BY UTILIZING GENETIC ALGORITHM

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Abstract

In this works, surface roughness for end milling of Ti-6Al-4V under wet conditions were optimized. Genetic algorithm (GA) was used for finding the optimum cutting conditions such as cutting speed (V), feed per tooth (f_z), and radial rake angle (γ_o). The optimized results were compared to that had been generated using response surface methodology (RSM). It has been proven that GA-results showed more accurate than RSM-results which have been validated using data taken according to the design of experiments (DOE).

Keywords: Surface Roughness, End Milling, Titanium Alloys, Genetic Algorithm (GA), Response Surface Methodology (RSM).

1. Introduction

Titanium alloys are used widely known as difficult to cut materials, especially at higher cutting speeds, due to their several inherent properties. Among the titanium alloys, Ti-6Al-4V is the most widely used in the aerospace, chemical and ship building industry because of their superior mechanical properties, heat and corrosions resistance, so it has been chosen as the workpiece in this study.[1].

Due their low machinability of the alloy under study, selecting the machining conditions and parameters is crucial. According to the past reports, the range of feeds and cutting speeds which provide a satisfactory tool performance is very limited. On the other hand, adequate tool, coating, geometry and cutting flow materials should be used [2].

The study of Lo and Chen [3] has pioneered in finding of the optimum cutting conditions for machining processes using response surface methodology, which are followed by [4]-[5]. After that, [6]-[8] have begun with the researches using titanium alloy as workpiece. Recently, it has begun to explore the study using non-conventional algorithm in [9]-[11]. Furthermore, according to the previous studies, there is no researcher employed genetic algorithm in searching the optimum cutting conditions for machining of aerospace materials. Base on these facts, it is necessary to take part in contribution of providing such lack in information

2. Procedure of Experiments

Based on [12] experiment, a CNC MAHO 700S machining centre was used for experimentation, while side-milling process was conducted with a constant axial depth of cut a_a 5 mm and radial depth of cut a_e 2 mm under flood coolant with a 6% concentration. The reference workpiece material of Ti-6Al-4V, which was a rectangular block of 110 mm x 55 mm x 150 mm, was used for cutting force measurements. Surface roughness of the machined surface was measured using portable Taylor Hobson Surftronic +3. Before conducting the measurement, the instrument was calibrated using a standard specimen roughness supplied to ensure the consistency and accuracy of surface roughness values. There are three cutting parameters used in this study, i.e. cutting speed, feed, and radial rake angle. Machining conditions used in this optimization study for each cutting parameters are:

- Cutting speed V : 130 - 160 m/min.
- Feed per tooth f_z : 0,03 - 0,07 mm/teeth.
- Radial rake angle γ : 7^o - 13^o.

Cutting parameters (cutting speed, feed per tooth, and radial rake angle) are coded using transformed equation (1) according to circumstance of limitation of the milling machine.

$$x = \frac{\ln x_n - \ln x_{n0}}{\ln x_{n1} - \ln x_{n0}} \tag{1}$$

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 shows in Table I.

Table I. Levels of Independent Variables for End Milling Ti6Al4V

Independent Variable	Level in coded form				
	-α	-1	0	1	α
$V(mm.\min^{-1})x1$	124.53	130	144.22	160	167.03
$f_z\ (mm.tooth^{-1})x2$	0.025	0.03	0.046	0.07	0.083
$\gamma o(°)x3$	6.2	7.0	9.5	13.0	14.8

3. **Research Methodology**

The mathematical model used in this study is the 2nd CCD surface roughness model. Genetic algorithm results were compared to the response surface methodology. The mathematical model shown by equation (2)

$$\hat{y}_2 = -1.0810 - 0.12272x_1 + 0.23941x_2 + 0.071218x_3 + 0.10751x_1x_2 - 0.016614x_1x_3 - 0.020616x_2x_3 - 0.0752385x_1^2 + 0.12822x_2^2 + 0.009294x_3^2 \tag{2}$$

Thus model is valid for end milling of titanium alloy, Ti-6Al-4V using TiAlN coated carbide tools under wet conditions with the following range of respective cutting speed (V, f_z, and γ): $130 \le V \le 160$ m/min; $0.03 \le f_z \le 0.07$ mm/tooth; $7 \le \gamma_o \le 13$ (^{o}) for std. order 1 to std. order 12.

The 2nd order CCD surface roughness model was also used for std. order 13 to std. order 24 with the following range of respective cutting speed, feed per tooth, and radial rake angle (V, f_z, and γ): $124.53 \le V \le 167.03$ m/min; $0.025 \le f_z \le 0.083$ mm/tooth; $6.2 \le \gamma \le 14.8$ (^{o}).

Genetic Algorithm (GA) was inspired from biological evolution where the evolution is the method of searching among enormous number possibilities for solutions. GA is the algorithm for searching, which is based on selection and genetic mechanism.

The solution found by GA is coded to binary numbers called chromosomes. The fitness value of each chromosome is evaluated by an objective function. Selecting of solutions are usually conducted in pairs through the application of genetic operator, the selected individuals are then reproduced. These operators are applied to copulate of individuals with a given probability, and result in new offspring. The offspring from reproduction are then evaluated by mutation and elitism probability, and then these new individuals are prime population for the next generation. Selection, reproduction and evaluation processes are repeated until some termination criteria are achieved. The flow chart of GA method is showed by figure 1.

To solve the problem in this optimization study, it is a crucial part to select the following parameters, i.e. population size, maximum number of generation, total string length, crossover

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probability, mutation probability, and elitism probability. It is important to acquire the best solutions.
Parameters used in this study using GA that must be manually entered, are [13]:

- Population size = 20
- Maximum generation = 15
- Crossover probability (*Pc*) = 0.45
- Mutation probability (*Pm*) = 0.03
- Elitism probability (*Pe*) = 0.25

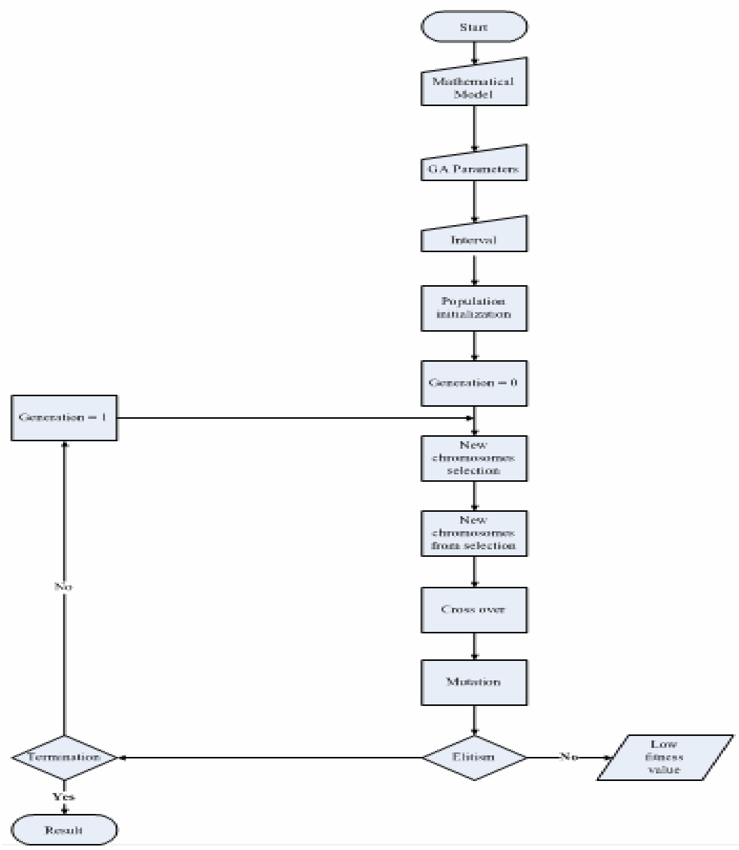

Figure 1: Genetic Algorithm Flow Chart

4. **Results and Discussion**

Surface roughness experimental results using TiAlN coated solid carbide tools were showed in Table II. This results were used in validating the comparison between response surface methodology and genetic algorithm.

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Table II: Surface Roughness Results using TiAlN Coated Solid Carbide Tools

Std Oder	Type	*V* (m/min)	*fz* (mm/ tooth)	γ (^{0})	R_a (μm)
1	Factorial	-1	-1	-1	0.320
2	Factorial	1	-1	-1	0.216
3	Factorial	-1	1	-1	0.456
4	Factorial	1	1	-1	0.426
5	Factorial	-1	-1	1	0.408
6	Factorial	1	-1	1	0.232
7	Factorial	-1	1	1	0.482
8	Factorial	1	1	1	0.468
9	Center	0	0	0	0.368
10	Center	0	0	0	0.360
11	Center	0	0	0	0.324
12	Center	0	0	0	0.304
13	Axial	-1.1412	0	0	0.348
14	Axial	-1.1412	0	0	0.344
15	Axial	1.1412	0	0	0.256
16	Axial	1.1412	0	0	0.246
17	Axial	0	-1.1412	0	0.308
18	Axial	0	-1.1412	0	0.318
19	Axial	0	1.1412	0	0.584
20	Axial	0	1.1412	0	0.656
21	Axial	0	0	-1.1412	0.316
22	Axial	0	0	-1.1412	0.300
23	Axial	0	0	1.1412	0.386
24	Axial	0	0	1.1412	0.396

Table III and IV shows the optimization result of RSM and GA, and then compared to find out root mean square error (RMSE) of RSM and GA method.

Table III: The Optimization Result for RSM

No	V (m/min)	*fz* (mm/tooth)	γ (^{0})	R_a (μm)
1	159.33	0.03045	7.2326	0.21481
2	159.98	0.03028	7.9169	0.21428
3	159.47	0.0321	7.0401	0.21551
4	159.93	0.03007	7.6013	0.21291
5	159.99	0.03228	7.1133	0.21354
6	159.92	0.0317	7.4418	0.21433
7	159.75	0.03132	7.7296	0.21592
8	159.86	0.03056	7.0885	0.21711
9	160	10.03	8.7209	0.21759

No	V (m/min)	*fz* (mm/tooth)	γ (^{0})	R_a (μm)
10	160	0.03	12.344	0.23923

Table IV: The Optimization Results for GA

NO	V (m/min)	*fz* (mm/tooth)	γ (^{0})	R_a (μm)
1	159.31077	0.03072	7.04320	0.21650
2	159.05320	0.03072	7.04320	0.21730
3	157.45360	0.03112	7.11069	0.22498
4	157.27858	0.03342	7.50328	0.24090
5	153.24534	0.03196	7.25429	0.24460
6	151.33655	0.03108	7.10413	0.24566
7	143.90691	0.03196	7.25429	0.28051
8	143.41317	0.03196	7.25429	0.28262
9	141.04102	0.03152	7.18049	0.29050
10	141.04102	0.03196	7.25429	0.29308
11	150.96983	0.03837	8.32347	0.29357
12	142.66135	0.03528	7.81485	0.30576
13	157.37397	0.04375	9.18722	0.30847
14	134.42906	0.03215	7.28782	0.32647
15	149.16468	0.04422	9.26100	0.33529
16	159.82684	0.04914	10.02586	0.33754
17	143.90691	0.04914	10.02586	0.37926
18	145.17804	0.05057	10.24405	0.38343
19	133.90007	0.04811	9.86680	0.40634
20	144.48995	0.05823	11.39089	0.42599

From Table III and IV, it is recognized that the minimum surface roughness value found by RSM method is 0.21481(μm), then minimum surface roughness value by GA method is 0.21650(μm),. Minimum surface roughness value delivered by experimental result (see Table 2) is 0.216 (μm). From these results, it proven that optimization using GA is closer to experimental result than RSM.
Results comparison of RSM and GA to experimental data from the previous research using their RMSE is shown in Table V.

Table V: Validation of RSM and GA using Experimental Results

Std Order	Experimental R_a	RSM R_a	GA R_a	Estimated Error RSM	Estimated Error GA
1	0.320	0.3219049	0.3215524	0.0000036	0.0000024
2	0.216	0.2099825	0.2179630	0.0000362	0.0000039
3	0.456	0.4367183	0.4430961	0.0003718	0.0001665
4	0.426	0.4379463	0.4281260	0.0001427	0.0000045
5	0.408	0.3998751	0.3999555	0.0000660	0.0000647
6	0.232	0.2440722	0.2348129	0.0001457	0.0000079
7	0.482	0.4995563	0.4856051	0.0003082	0.0000130
8	0.468	0.4687513	0.4691129	0.0000006	0.0000012
9	0.368	0.3392561	0.3396366	0.0008262	0.0008045

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Std Order	Experimental R_a	RSM R_a	GA R_a	Estimated Error RSM	Estimated Error GA
10	0.360	0.3392561	0.3396366	0.0004303	0.0004147
11	0.324	0.3392561	0.3396366	0.0002327	0.0002445
12	0.304	0.3392561	0.3396366	0.0012430	0.0012700
13	0.348	0.3491629	0.3498689	0.0000014	0.0000035
14	0.344	0.3491629	0.3498689	0.0000267	0.0000344
15	0.256	0.2467652	0.2475135	0.0000853	0.0000720
16	0.246	0.2467652	0.2475135	0.0000006	0.0000023
17	0.308	0.3125038	0.3126502	0.0000203	0.0000216
18	0.318	0.3125038	0.3126502	0.0000302	0.0000286
19	0.584	0.6150872	0.6145457	0.0009664	0.0009330
20	0.656	0.6150872	0.6145457	0.0016739	0.0017185
21	0.316	0.3125069	0.3129054	0.0000122	0.0000096
22	0.300	0.3125069	0.3129054	0.0001564	0.0001665
23	0.386	0.3822441	0.3838655	0.0000141	0.0000046
24	0.396	0.3822441	0.3838655	0.0001892	0.0001472
Mean Square Error (MSE)				0.0002910	0.0002558
RMSE				0.0170584	0.0159944

Overall RMSE for RSM is 0.0170584 when that for GA is 0.0159944. It means, the optimization using GA is more accurate than RSM when validated using experimental results. Results comparison of RSM and GA to experimental data from the previous research using their RMSE is shown in Figure 2.

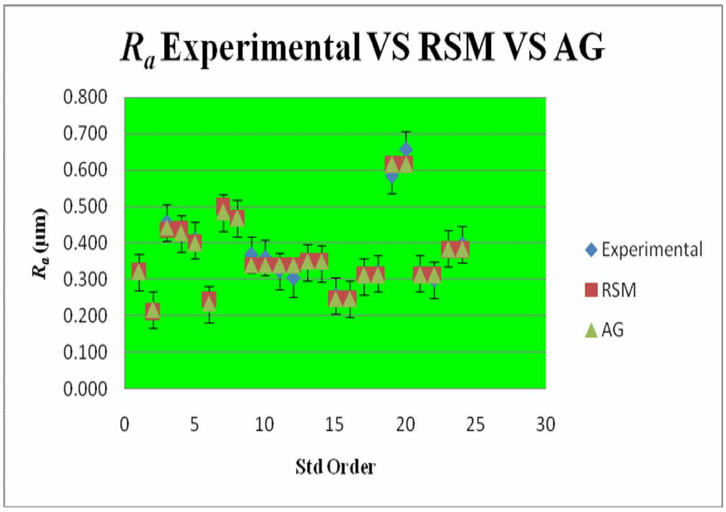

Figure 2: Results Comparison of RSM and GA Validated using Experimental Results.

5. Conclusions

1) Overall performance of optimizing the cutting conditions using genetic algorithm has shown slightly better results than those using response surface methodology. This can be recognized from the root mean squared error (RMSE) of GA which is 0.0159944, when compared to the RMSE of RSM 0.0170584.

2) Additionally GA showed also more precise than RSM in finding of the minimum surface roughness value.
3) Genetic algorithm can accomplish the optimization of surface roughness in machining of aerospace materials with adequate accuracy, which is required in industry.
4) The optimum cutting condition found using genetic algorithm is as follows : cutting speeds V = 159.31 m/min, feed per tooth f_z = 0.0307 mm/tooth and radial rake angle $\gamma_0 = 7.04^0$

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