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UTILIZATION OF GENETIC ALGORITHM FOR CUTTING FORCE OPTIMIZATION WHEN MACHINING Ti-6Al-4V USING TiAlN COATED END MILLS

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ABSTRACT-

This study deals with cutting force optimization in end milling Ti-6Al-4V using TiAlN coated solid carbide tools. Genetic Algorithm (GA) was utilized for finding the optimum cutting conditions such as cutting speed (V), feed per tooth (f_z), and radial rake angle (γ_o). The results were compared to that had been generated using Response Surface Methodology (RSM). It was found that GA-results are more accurate than RSM-results which have been validated using data taken from the design of experiments (DOE).

Keywords:

Cutting Force, End Milling, Titanium Alloys, Genetic Algorithm, Response Surface Methodology

1. INTRODUCTION

Titanium alloys are used widely in the aerospace, chemical and ship building industry because of their superior mechanical properties, heat and corosions resistance. Titanium alloy, however are materials that are extremely difficult to machine [1].

Due to 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].

For selecting the optimum cutting conditions in machining processes was initiated using Response Surface Methodology by [3], followed by [4]-[6] and recently was began to explore the very limited study using non-conventional algorithm in by [7]-[9]. None of previous studies employed genetic algorithm for finding the optimum cutting conditions in machining of aerospace materials. Therefore the aim of this study is to contribute in providing such lack of information.

2. EXPERIMENTAL SET-UP

Based on [6] 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.

The end mill was clamped to the tool holder with a constant 22 mm overhang. The TiAlN coated grade K-30 solid carbide end milling with different radial rake angle according to design of experiment, were used in the experiments. To avoid the influence of tool wear, the forces data (F_x , F_y , F_z) were recorded during the initial cut when the end mill was still new without wear. The recording of cutting force was carried out using multi component force measuring system consisting of the following elements:

- A 3-component dynamometer comprising of basic unit (Kistler, Type 9265B) and screwed-on working adapter for milling (Kistler, Type 9443B)
- A multi channel charge amplifier (Kistler, Type 5019A)
- A data acquisition system consisting of a personal computer (PC) equipped with an A/D board as well as the DynoWare software (Kistler, Type 2825 D1-2, version 2.31)

Machining condition used in this experiment :

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

Machining condition coded by equation (1) :

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

Result from the equation (1) are :

Table 1: Levels of Independent Variables for Ti-6Al-4V.

Independent Variables	Level in coded from				
	-1.4142	-1	0	1	1.4142
$V(\text{m} \cdot \text{min}^{-1})$ x_1	124.53	130	144.22	160	167.03
$f_z(\text{mm} \cdot \text{th}^{-1})$ x_2	0.025	0.03	0.046	0.07	0.083
$\gamma(^{\circ})$ x_3	6.2	7	9.5	13	14.8

1.1. Results of Experiment

Experimental results from Design of Experiment (DOE) showed by Table 2. From the result known that the most significant factor that affected the cutting force was factor feed, followed by interaction feed and radial rake angle, interaction speed and feed and lastly factor cutting speed [10].

Table 2: Cutting Force F_c when using TiAlN Coated Carbide Tools.

Std Order	Type	$V(\text{m} \cdot \text{min}^{-1})$	$f_z(\text{mm} \cdot \text{th}^{-1})$	$\gamma(^{\circ})$	$F_c(\text{N})$
1	Factorial	-1	-1	-1	82.760
2	Factorial	1	-1	-1	88.450
3	Factorial	-1	1	-1	116.53
4	Factorial	1	1	-1	106.57
5	Factorial	-1	-1	1	64.380
6	Factorial	1	-1	1	66.340
7	Factorial	-1	1	1	129.92
8	Factorial	1	1	1	107.38
9	Center	0	0	0	80.880
10	Center	0	0	0	67.990
11	Center	0	0	0	74.800
12	Center	0	0	0	80.070
13	Axial	-1.4142	0	0	94.400
14	Axial	-1.4142	0	0	82.870
15	Axial	1.4142	0	0	68.760
16	Axial	1.4142	0	0	79.800
17	Axial	0	-1.4142	0	52.230
18	Axial	0	-1.4142	0	78.430
19	Axial	0	1.4142	0	103.13
20	Axial	0	1.4142	0	96.740
21	Axial	0	0	-1.4142	101.56
22	Axial	0	0	-1.4142	107.11
23	Axial	0	0	1.4142	65.040
24	Axial	0	0	1.4142	115.04

3. RESEARCH METHODOLOGY

Optimization in this study is to find minimum cutting force using Genetic Algorithm method. With this method hopefully optimum cutting condition can investigated better than RSM method from the previous research. GA is the algorithm based on the biology [11]. Generally there are eight components of GA: coding scheme, fitness value, parent selection, crossover, mutation, elitism, generational replacement, and termination criteria [12]. In this study MATLAB software used to apply GA, because in this software there are many mathematical operations that can make this optimization easier to conduct [13].

According to [6] mathematical model used for optimizing the cutting force in this study:

- 3FI Cutting Force Model

$$y = 4.5285 - 0.02293x_1 + 0.21403x_2 - 0.0528x_3 - 0.04705x_1x_2 + 0.08189x_2x_3 \quad (2)$$

- 1st order CCD Cutting Force Model

$$y_1 = 4.4615 - 0.02293x_1 + 0.21403x_2 - 0.0528x_3 \quad (3)$$

Both models are valid for end milling of titanium alloy, Ti6Al4V using TiAlN coated carbide tools under wet conditions with the following range of respective cutting speed (V , f_z , and γ_o): $130 \leq V \leq 160 \text{ m/min}$; $0.03 \leq f_z \leq 0.07 \text{ mm/teeth}$; $7 \leq \gamma_o \leq 13 (^{\circ})$. Experimental data used to validate the optimization result data are no. 1 to no. 12.

- 2nd order CCD Cutting Force Model

$$y_2 = 4.3182 - 0.042812x_1 + 0.1857x_2 - 0.05948x_3 + 0.04239x_1^2 + 0.03626x_2^2 + 0.12237x_3^2 - 0.04705x_1x_2 - 0.01721x_1x_3 + 0.08189x_2x_3 \quad (4)$$

Model is valid for end milling of titanium alloy, Ti6Al4V using TiAlN coated carbide tools under wet conditions with the following range of respective cutting speed (V , f_z , and γ_o): $124.53 \leq V \leq 167.03 \text{ m/min}$; $0.025 \leq f_z \leq 0.083 \text{ mm/teeth}$; $6.2 \leq \gamma_o \leq 14.8 (^{\circ})$. Experimental data used to validate the optimization result data are no. 1 to no. 24.

There are six parameters that must be determined in GA method [13]:

- Population size = 80
- Maximum generation = 10
- Crossover probability (P_c) = 0.8
- Mutation probability (P_m) = 0.03
- Elitism probability (P_e) = 0.5

Flow chart for Genetic Algorithm seen from figure 1 :

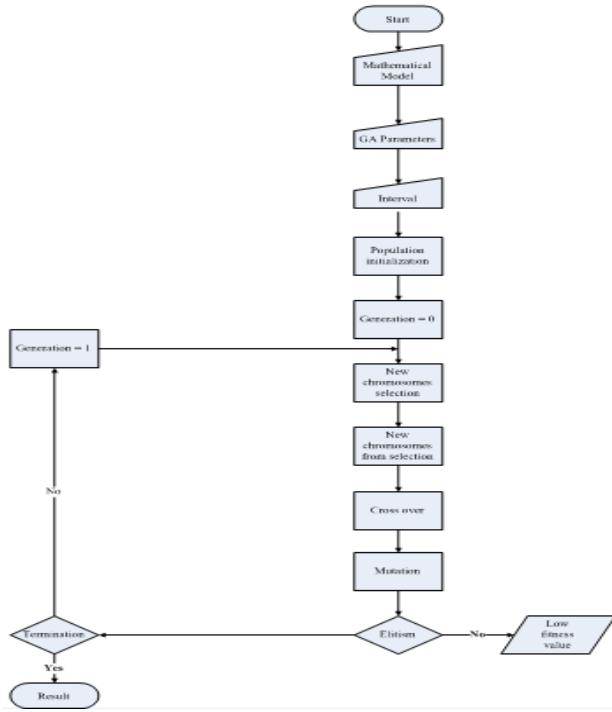


Figure 1: Genetic algorithm flow chart.

Table 4: RSM validation test results for 1st order CCD Cutting Force Model about experimental results to std. order 1-12.

Std Oder	Experimental	RSM	SE
	F_c (N)	F_c (N)	
1	82.76	75.4296	53.7345
2	88.45	72.0485	269.0080
3	116.53	115.7300	0.6400
4	106.57	110.5425	15.7807
5	64.38	67.8704	12.1829
6	66.34	64.8282	2.2857
7	129.92	104.1321	665.0173
8	107.38	99.4644	62.6564
9	80.88	86.6173	32.9170
10	67.99	86.6173	346.9777
11	74.8	86.6173	139.6495
12	80.07	86.6173	42.8676
Mean Square Error (MSE)			136.9764
Root Mean Square Error (RMSE)			11.7037

Table 5: RSM validation test results for 2nd order CCD Cutting Force Model about experimental results to std. order 1-12.

Std Oder	Experimental	RSM	SE
	F_c (N)	F_c (N)	
1	82.76	85.9222	9.9994
2	88.45	89.6881	1.5329
3	116.53	116.1825	0.1208
4	106.57	100.4699	37.2114
5	64.38	67.0288	7.0160
6	66.34	65.3121	1.0565
7	129.92	125.7634	17.2777
8	107.38	101.5202	34.3370
9	80.88	75.0534	33.9491
10	67.99	75.0534	49.8918
11	74.8	75.0534	0.0642
12	80.07	75.0534	25.1662
Mean Square Error (MSE)			18.1352
Root Mean Square Error (RMSE)			4.2585

4. RESULTS AND DISCUSSION

In this study 3 mathematical models of cutting force, such as ; 3FI Cutting Force Model, 1st order CCD Cutting Force Model and 2nd order CCD Cutting Force Model, were validated using experimental data.

Table 3: RSM validation test results for 3FI Cutting Force Model about experimental results to std. order 1-12.

Std Oder	Experimental	RSM	SE
	F_c (N)	F_c (N)	
1	82.76	83.5161	0.5718
2	88.45	87.6437	0.6501
3	116.53	119.5124	8.8946
4	106.57	103.9032	7.1117
5	64.38	63.7941	0.3433
6	66.34	66.9469	0.3683
7	129.92	126.6719	10.5504
8	107.38	110.1276	7.5495
9	80.88	92.6195	137.8165
10	67.99	92.6195	606.6136
11	74.8	92.6195	317.5356
12	80.07	92.6195	157.4906
Mean Square Error (MSE)			104.6247
Root Mean Square Error (RMSE)			10.2286

Table 6: RSM validation test results for 2nd order CCD Cutting Force Model about experimental results to std order 13-24.

Std Oder	Experimental	RSM	SE
	F_c (N)	F_c (N)	
13	94.4	83.2846	123.5531
14	82.87	83.2846	0.1719
15	68.76	75.5314	45.8524
16	79.8	75.5314	18.2206
17	52.23	63.6565	130.5656
18	78.43	63.6565	218.2554
19	103.13	97.2557	34.5074
20	96.74	97.2557	0.2659
21	101.56	104.2771	7.3827
22	107.11	104.2771	8.0252
23	65.04	88.1305	533.1713
24	115.04	88.1305	724.1211
Mean Square Error (MSE)		153.6744	
Root Mean Square Error (RMSE)		12.3965	

Based on validation test results above, it is proven that the 2nd order CCD Cutting Force Model is the most accurate model compared to 1st order CCD Cutting Force Model and 3FI Cutting Force Model. Because of that, the 2nd order CCD Cutting Force Model was used to optimize cutting force.

Table 7 and 8 show the validation test to RSM and GA method using 2nd order CCD Cutting Force Model

Table 7: Validation test results to GA method for 2nd order CCD Cutting Force Model about experimental results to std order 1-12.

Std Oder	Experimental	GA	SE
	F_c (N)	F_c (N)	
1	82.76	83.0156	0.0653
2	88.45	88.2360	0.0458
3	116.53	115.1370	1.9404
4	106.57	101.8700	22.0900
5	64.38	64.3941	0.0074
6	66.34	65.5204	0.6717
7	129.92	124.2360	32.3079
8	107.38	102.1360	27.4995
9	80.88	76.7339	17.1901
10	67.99	76.7339	76.4558
11	74.8	76.7339	3.7400
12	80.07	76.7339	11.1296
Mean Square Error (MSE)		16.0953	
Root Mean Square Error (RMSE)		4.0118	

Table 8: Validation test results to GA method for 2nd order CCD Cutting Force Model about experimental results to std order 13-24.

Std Oder	Experimental	GA	SE
	F_c (N)	F_c (N)	
13	94.4	88.9011	30.2378
14	82.87	88.9011	36.3743
15	68.76	74.4247	32.0885
16	79.8	74.4247	28.8942
17	52.23	67.0350	219.1871
18	78.43	67.0350	129.8467
19	103.13	99.3609	14.2063
20	96.74	99.3609	6.8690
21	101.56	101.1320	0.1832
22	107.11	101.1320	35.7365
23	65.04	89.8755	616.8031
24	115.04	89.8755	633.2511
Mean Square Error (MSE)		148.6398	
Root Mean Square Error (RMSE)		12.1918	

Optimization of cutting force using RSM and GA method seen by following table.

Table 9: Optimization results using RSM for 2nd order CCD Cutting Force Model

No	V (m/min)	f_z (mm/mata potong)	$\gamma_o(^\circ)$	F_c (N)
1	146.01	0.03000	11.750	62.0413
2	145.93	0.03000	11.700	62.0413
3	146.22	0.03018	11.766	62.1096
4	149.34	0.03000	12.058	62.2277
5	151.54	0.03000	12.063	62.4396

Table 10: Optimization results using GA for 2nd order CCD Cutting Force Model

No	V (m/min)	f_z (mm.th ⁻¹)	$\gamma_o(^\circ)$	F_c (N)
1	136.976	0.03028	12.9947	64.3941
2	130.225	0.03184	12.9886	68.8004
3	132.261	0.03198	12.9886	67.9847
4	134.330	0.03211	12.6975	66.7519
5	135.037	0.03038	12.8868	64.8687

F_c minimum using the 2nd order CCD Cutting Force Model according to GA is 64.3941 N and RSM is 62.0413 N.

Overall validation test results using GA and RSM method about experimental data showed by table 11.

Table 11: Validation test results method RSM and GA for 2nd order CCD Cutting Force Model about experimental results to std order 1-24.

Std Order	Experimental	RSM	GA	RSM	GA
	F_c (N)	F_c (N)	F_c (N)	SE	SE
1	82.76	85.9222	83.0156	9.9995	0.0653
2	88.45	89.6881	88.236	1.5329	0.0458
3	116.53	116.1825	115.137	0.1208	1.9404
4	106.57	100.4699	101.87	37.2112	22.0900
5	64.38	67.0288	64.3941	7.0161	0.0002
6	66.34	65.3121	65.5204	1.0566	0.6717
7	129.92	125.7634	124.236	17.2773	32.3079
8	107.38	101.5202	102.136	34.3373	27.4995
9	80.88	75.0534	76.7339	33.9493	17.1901
10	67.99	75.0534	76.7339	49.8916	76.4558
11	74.8	75.0534	76.7339	0.0642	3.7400
12	80.07	75.0534	76.7339	25.1663	11.1296
13	94.4	83.2846	88.9011	123.5521	30.2379
14	82.87	83.2846	88.9011	0.1719	36.3742
15	68.76	75.5314	74.4247	45.8519	32.0888
16	79.8	75.5314	74.4247	18.2209	28.8939
17	52.23	63.6565	67.035	130.5649	219.1880
18	78.43	63.6565	67.035	218.2563	129.8460
19	103.13	97.2557	99.3609	34.5074	14.2061
20	96.74	97.2557	99.3609	0.2659	6.8691
21	101.56	104.2771	101.132	7.3826	0.1832
22	107.11	104.2771	101.132	8.0253	35.7365
23	65.04	88.1305	89.8755	533.1712	616.8021
24	115.04	88.1305	89.8755	724.1212	633.2521
MSE			85.90	82.36	
RMSE			9.27	9.08	

Although the optimization using RSM and GA have shown different results, they are still in tolerance, which is shown in Figure 2.

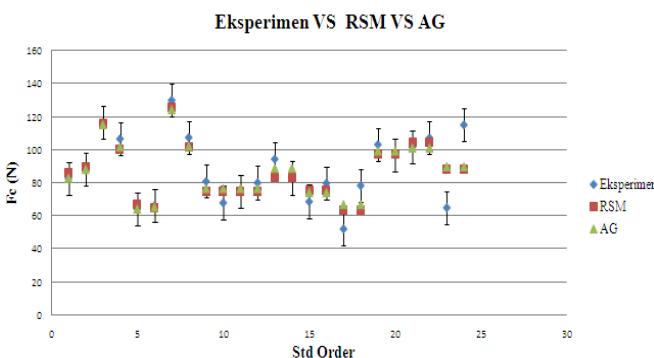


Figure 2: Cutting force results using GA and RSM compare to experimental results when end milling Ti-6Al-4V.

5. CONCLUSIONS

- Overall performance of optimization using genetic algorithm showed better results than those using response surface methodology. RMSE accuracy of GA is about 9.08 compared to accuracy of RSM = 9.27.
- In case of finding the minimum cutting force value, genetic algorithm delivered better results than that using response surface methodology (RSM-result $F_c = 67.0288$ N, while GA-result $F_c = 64.3941$ N).
- Genetic algorithm can accomplish the optimization in machining of aerospace materials with adequate accuracy, which is required in industry.
- The optimum cutting condition found using genetic algorithm is as follows: cutting speeds $V = 136.976$ m/min, feed per tooth $f_z = 0.03028$ mm/tooth and radial rake angle $\gamma_o = 12.9947^\circ$.

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