Investigation of Surface Roughness, Tool Wear and Chip Reduction Coefficient during Machining of Titanium Alloy with PVD Al-Ti-N Coating Carbide Insert

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Abstract

Titanium alloy is the widely used material in most of the manufacturing industries. The components and products made from titanium alloy are broadly use in aerospace, biomedical, automobile and marine sectors due to its superior material properties of good strength-to-weight ratio and corrosion resistance. However, conventional machining of titanium alloy is a challenging task due to its low thermal conductivity and high chemical reactivity properties. In this study, machining of the titanium alloy of grade 5 (Ti-6Al-4V) has been carried out by using advanced PVD Al-Ti-N coating carbide insert (KC5010) to study the effect of the cutting variables on surface roughness, tool wear and chip reduction coefficient (CRC). The experiments are conduct as per the orthogonal array layout of Taguchi L27. Desirability function analysis (DFA) approach is use to analyze the performance index of the output responses by obtaining the composite desirability value. The optimum parameter setting for the responses is obtained. The cutting variable influencing the responses and the percentage contribution of that cutting is determine through analysis of variance (ANOVA) and mean response of the composite average desirability value. Confirmation test was perform to validate the optimum cutting condition. It is observed that, the optimum parameters setting obtained from DFA approach has improve the machining performance of titanium alloy during machining with PVD coated cutting tool.

Keywords: Machining, Titanium alloy, Tool wear, surface roughness, Desirability function analysis, Analysis of variance

1. INTRODUCTION

In the era of advanced manufacturing process, the components must meet the dimensional accuracy and tolerance. To meets, the challenge machining plays an important role in manufacturing process. Now a day's demand of titanium alloy in the manufacturing industries such as aerospace, automobile and marine sectors is high due to high strength to weight ratio and good corrosion resistance properties. However, the conventional machining of titanium alloy is a major challenging task. The machining of titanium alloy is difficult due to its poor thermal conductivity and high chemical reactivity properties [1]. To achieve better surface finish with less tool wear rate is the most important objective for the manufacturing industries. During machining other responses also has to be studied to save machining time, material cost and per hour machining cost. In such conditions, it is very problematic to find out the best possible combination of the cutting variables, that satisfying all the required responses with its optimum outcomes. To overcome such type of multi-response problem and to find out an optimum parametric setting for overall responses, researchers have suggested many different types of multi-objective optimization approaches and techniques such as Grey relational analysis (GRA), Principal component analysis (PCA), Response surface methodology (RSM) and desirability function analysis (DFA) [2-4].

Researcher have used different types of multi-objective optimization approaches in different types of manufacturing process and systems such as Sarikaya and Gullu studied the effect of surface roughness and average maximum height of the profile during turning of AISI 1050 steel. The optimal operating parameters were determined using the desirability function analysis Results indicates that feed rate is the most effective parameter on the surface roughness. [5]. Bhattacharya et al. studied the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA approach. The results revealed that, cutting speed is the most effective parameter on the surface roughness and power consumption [6]. Nihat tosun optimized surface roughness and burr height during drilling using grey relational analysis approach and suggested that, this approach can be successfully applied to various types of machining and manufacturing process in which multiple parameters quality characteristics were to be optimized [7]. Ramanujam et. al. optimized the surface roughness and power consumption during machining of Al-15%SiCp composites using desirability function analysis. Results founded that, the performance characteristics of the responses were enhanced using the DFA method [8].

From the literature survey it can be said that, most of the work has been carried out by considering multi-objective problem along with various types of multi-objective optimization methodologies to find out optimal parametric setting of the cutting variables satisfying the performance characteristics of the responses. Therefore, in this paper, the multi-objective optimization method, namely desirability function analysis has been used to optimize the surface roughness, tool wear and chip reduction coefficient by finding out the optimal parametric conditions of the cutting variables (cutting speed(v), feed(f) and depth of cut(d)) during turning of titanium alloy of grade 5 (Ti-6Al-4V) with KC5010 cutting inserts. The optimum parametrical setting for the desired responses is predicted and validate with the confirmation test. Further, from the mean responses and ANOVA analysis the most significant cutting variables affecting the responses was found.

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2. EXPERIMENTAL DETAILS

The experiment is carried out on the high precision lathe machine, model NH26 of HMT make. The machine has a variable spindle speed of 45 rpm to 1020 rpm. The spindle power of the lathe machine is 11 KW. In this experiment, the turning operation is carried out using Taguchi orthogonal Ti-6Al-4V. The experiment setup is shown in Fig. 1.

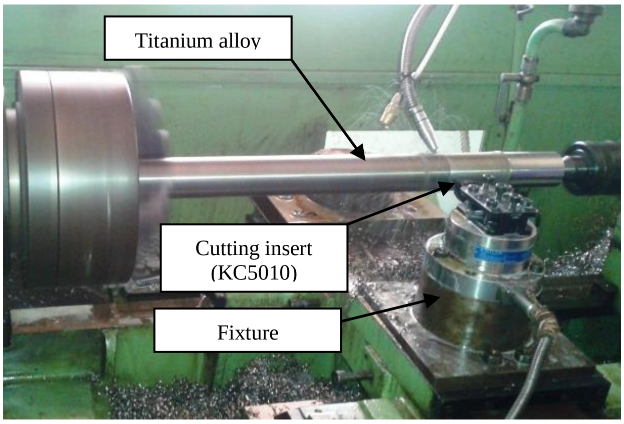

Fig. 1 Experiment setup

The diameter and length of the titanium alloy considered for machining is 50mm and 600mm respectively. The cutting inserts selected to machine Ti-6Al-4V is KC5010 of Kennametal make. The ISO grade of the cutting inserts is SNMG120408. Selection of KC5010 cutting inserts for machining titanium alloy done because this grade of cutting inserts has an advanced PVD Al-Ti-N coating over the surface of the deformation-resistant unalloyed carbide substrate. This coating helps to achieve an increase in speeds by 50-100 % during machining. The effects of process parameters on the surface roughness of the machined surface, tool wear of the cutting inserts and chip reduction coefficient were studied. The surface roughness of each run was measured using Taylor Hobson Surtronic 3+ surface roughness tester. The flank wear of the cutting inserts and chip reduction coefficient after each experimental run was measured with the optical microscope.

3. DESIGN OF EXPERIMENT

The experiment is carried out using Taguchi orthogonal array layout. The number of experiments to perform is based on the selection of number of cutting variables and the range of the cutting variables. In this experiment, the cutting variables considered for the machining were cutting speed, feed and depth of cut. The cutting variables were also varies with three levels. Total 27 numbers of experiments is done as per the L27 orthogonal array layout as shown in Table 1.

Table 1. Experimental layout with data

	Cutting variables			Responses		
Sl.no	cutting speed	feed	depth of cut	RA	TW	CRC
1	95	0.04	0.4	1.887	0.126	1.035
2	95	0.04	0.8	0.967	0.296	1.812
3	95	0.04	1.6	0.833	0.268	2.071
4	95	0.08	0.4	1.173	0.246	1.294
5	95	0.08	0.8	0.920	0.263	1.941
6	95	0.08	1.6	0.867	0.196	1.941
7	95	0.16	0.4	1.293	0.237	1.294
8	95	0.16	0.8	1.013	0.174	1.618
9	95	0.16	1.6	1.620	0.248	1.876
10	124	0.04	0.4	1.007	0.210	1.294
11	124	0.04	0.8	1.173	0.258	1.294
12	124	0.04	1.6	0.827	0.288	2.847
13	124	0.08	0.4	0.793	0.224	1.294
14	124	0.08	0.8	0.987	0.281	1.941
15	124	0.08	1.6	1.840	0.263	1.682
16	124	0.16	0.4	1.570	0.635	1.424
17	124	0.16	0.8	1.287	0.463	1.747
18	124	0.16	1.6	1.320	0.725	2.394
19	160	0.04	0.4	0.700	0.249	1.294
20	160	0.04	0.8	0.653	0.278	2.588
21	160	0.04	1.6	0.553	0.267	2.588
22	160	0.08	0.4	0.757	0.275	1.941
23	160	0.08	0.8	0.800	0.218	1.941
24	160	0.08	1.6	2.293	0.301	1.812
25	160	0.16	0.4	4.440	1.482	0.841
26	160	0.16	0.8	2.700	1.422	1.812
27	160	0.16	1.6	4.373	3.837	2.524

4. RESULTS AND DISCUSSION

4.1. Optimization using DFA methodology

Derringer and Suich [9] popularized this valuable method to optimize the multiple responses. In this multi-response optimization method [10], the individual desirability index of surface roughness, tool wear and chip reduction coefficient were calculated according to smaller the better criteria using Equation 1.[3]

$$d_i = \begin{cases} 1, & x \le x_{\min} \\ \left(\dfrac{x - x_{\max}}{x_{\min} - x_{\max}} \right)^r, & x_{\min} \le x \le x_{\max},\ r \ge 0 \\ 0, & x \ge x_{\min} \end{cases} \quad (1)$$

where, d_i represents the individual desirability index, $x_{\min}$ and $x_{\max}$ are the lowest and highest values of x. The target to be minimized is denoted by x . r depicts the weight, and the weight values are expressed as per the requirement of the decision maker. Using, the individual desirability indexes of each experimental run the composite desirability was calculate. The calculation of the composite desirability d_G is done using the Equation 2.

$$d_G = \left(d_1^{w_2} \times d_1^{w_2} \times .... \times d_i^{w_i}\right)^{1/w} \qquad (2)$$

where, w_i represents the weight assigned to each responses, w is the sum of all individual weights. The value of d_G closer to 1 is assumed to be the optimal parametric setting of corresponding input parameters. The desirability index of the surface roughness and tool wear, and the overall desirability index for each experimental run were shown in Table 3. The higher composite desirability value is select as the optimal parametric setting.

Table 2. Evaluated individual desirability and composite desirability

	Individual Desirability F (di)			composite desirability function
Sl.no	RA	TW	CRC	dG
1	0.657	1.000	0.903	0.920
2	0.894	0.954	0.516	0.855
3	0.928	0.962	0.387	0.813
4	0.840	0.968	0.774	0.921
5	0.906	0.963	0.452	0.836
6	0.919	0.981	0.452	0.840
7	0.810	0.970	0.774	0.916
8	0.882	0.987	0.613	0.888
9	0.725	0.967	0.484	0.820
10	0.883	0.977	0.774	0.929
11	0.840	0.964	0.774	0.921
12	0.930	0.956	0.000	0.000
13	0.938	0.974	0.774	0.937
14	0.888	0.958	0.452	0.833
15	0.669	0.963	0.581	0.840
16	0.738	0.863	0.710	0.873
17	0.811	0.909	0.548	0.847
18	0.803	0.839	0.226	0.700
19	0.962	0.967	0.774	0.940
20	0.974	0.959	0.129	0.657
21	1.000	0.962	0.129	0.660
22	0.948	0.960	0.452	0.841
23	0.936	0.975	0.452	0.841
24	0.552	0.953	0.516	0.796
25	0.000	0.635	1.000	0.000
26	0.448	0.651	0.516	0.728
27	0.017	0.000	0.161	0.000

It is observed from the Table 3 that, cutting speed at level 3, feed at level 1 and depth of cut at level 1 is the optimal parametric setting obtained using DFA approach. The effect of each individual cutting variable on the composite desirability at each level is calculated and the mean response of the composite desirability of all the machining parameters with its levels is shown in Table 3.

Table 3. Response table for the composite desirability

Machining parameter	Average composite desirability		
	speed	feed	depth
level 1	0.8677	0.744	0.8086
level 2	0.7644	0.8538	0.8229
level 3	0.607	0.6414	0.6076
Max-Min	0.2607	0.2124	0.2153
Rank	1	3	2
Total Mean of the composite desirability			0.74637

It is observed from the Table 3 that, cutting speed is the most influential cutting variable followed by depth of cut and feed during machining of titanium alloy with KC5010 cutting inserts.

4.2. Analysis of variance(ANOVA)

In ANOVA all the outputs was apportioned according to contribution of various inputs. The purpose of ANOVA is to reveal the percentage contribution of each of the cutting variables during machining operation and to detect the machining parameters that significantly affect the performance characteristics [11]. The result obtained from the ANOVA is tabulated in Table 4. From the ANOVA analysis, it observes that, the cutting speed is the most significant machining parameter for affecting the output responses. Simultaneously, the interaction between the cutting speed and feed affects the surface roughness, tool wear and chip reduction coefficient.

Table 4. Analysis of Variance for the composite desirability

Source	DF	Seq SS	Adj SS	Adj MS	F	%
v	2	0.3101	0.3101	0.15506	3.09	15.22
f	2	0.2032	0.2032	0.10159	2.02	9.97
d	2	0.2609	0.2609	0.13045	2.6	12.81
v*f	4	0.5065	0.5065	0.12662	2.52	24.86
v*d	4	0.1398	0.1398	0.03496	0.7	6.86
f*d	4	0.2151	0.2151	0.05378	1.07	10.56
Residual Error	8	0.4015	0.4015	0.05018		
Total	26	2.0371				

4.3. Confirmatory test

Confirmation test is carried out to validate the enhancement of the performance characteristics by using the initial setting of the machining parameters. The predicted composite desirability for the optimum parametric setting is calculated by the following Equation 3 [8].

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{q}\left(\overline{\gamma_i} - \gamma_m\right) \qquad (3)$$

Where, $\hat{\gamma}$ is the predicted composite desirability, γ_m is the total mean of the composite desirability value, $\overline{\gamma_i}$ is the mean of the composite desirability value at the optimum level and q is the total number of machining parameter considered for the machining operation.

Table 5 shows the confirmatory test carried out with an initial machining parameters of Cutting speed at 124 m/min, feed at 0.16 mm/rev and depth of cut at 1.6 mm with optimal parametric setting. The experimental values of surface roughness, tool wear and chip reduction coefficient of initial setting and the optimal setting was tabulated. The composite desirability value, the results of the predicted composite desirability value, and the improved composite desirability value were also tabulated. An improvement of 0.2401 is observed by using DFA approach.

Table 5 confirmation test

Initial machining parameters		Optimal machining parameters	
	Experiment	Experiment	Prediction
Setting Level	v2f3d3	v3f1d1	v3f1d1
Surface roughness	1.32	0.7	
Tool wear	0.725	0.249	
Chip reduction coefficient	2.394	1.294	
composite desirability value	0.6997	0.9398	0.8624
Improvement in composite desirability value			0.2401

It clearly shown that, the multiple cutting performance characteristics during machining of titanium alloy with KC5010 carbide cutting tool with the L27 Taguchi design combined with the DFA method greatly enhanced.

5. CONCLUSION

In this study, the L27 taguchi orthogonal array design is used for conducting the experimental runs. The DFA method is applied to optimize the responses for the cutting variables (cutting speed, feed and depth of cut) during machining of titanium alloy with KC5010. It is shown that, the multiple performance characteristics during machining of titanium alloy are improved by using the method proposed in this study. The optimal parametric setting obtained using DFA is cutting speed at 160 m/min, feed at 0.04 mm/rev and depth of cut at 0.4 mm. From the ANOVA and response tables, it is conclude that, cutting speed is the most significant cutting variable. The validation of the optimal parametric setting with initial parametric setting shows an improvement of 0.2401 respectively.

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