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Design and Optimization of Process Parameters during Turn-Milling Process of Titanium Alloy using GRA Method

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ABSTRACT

The machinability rating of an engineering material is the fundamental property of material which decides the increase and decrease of productivity, machining cost and optimization of material selection in design of mechanical parts. Therefore, this work focuses on the study of surface roughness parameter (Ra), tool temperature (T_t) and work temperature (T_w) while performing turn milling on the Ti alloy which is relatively a low machinability alloy for various combination of machining parameters like feed (f), depth of cut (doc) and spindle speed (N) using Taguchi philosophy with non-coated PVD tool inserts under wet conditions. Surface roughness tester and IR Gun are used to measure the roughness and temperature respectively.

Taguchi design of experiments (DOE) based on Orthogonal Arrays (OA) and Signal-to-noise ratio (S/N ratio) is used for experimental design. Responses thus generated are used to predict performance and significance of machining parameters combinations in Turn milling operation on a CNC turn milling using Analysis of Variance (ANOVA). Individual optimality of responses is carried out using S/N ratios of the responses and a multi-response optimization of responses is carried out using Grey Relational Analysis (GRA) for both the conditions of machining and better responses in wet conditions.

KEYWORDS: Design of Experiments, Taguchi, Grey Relational Analysis, Orthogonal Arrays, ANOVA

1. INTRODUCTION

Machinability is determined by two factors: a. Work material characteristics (such as microstructure, grain size, hardness, strength, and composition) and b. Physical qualities (like elasticity, conductivity, work hardening). The degree of difficulty in machining a metallic work under examination defines this attribute. This research looked examined Ti-6Al-4V, which is much stronger than commercially pure titanium while maintaining the same stiffness and thermal qualities and is also heat treatable. The act of acquiring information where variation is present, whether under the full control of the experimenter or not, is known as design of experiments (DOE). Taguchi's notion of orthogonal array, which restricts replication of experimental combinations, is particularly suited for DOE and identifying optimality of responses through the assessment of signal-to-noise ratios (SN ratios). Taguchi's optimization philosophy is the beginning point for every industrial process/product optimization, but this method is not capable of solving multi-response optimization problems, hence it can be combined with other methods such as Grey relational analysis (GRA).

Machining is used to make numerous metal items, but it can also be used to make other materials like wood, plastic, ceramics, and composites. A machinist is a person who specialises in machining. A machine shop is a room, building, or company where machining is done. Computer numerical control (CNC) is used to control the movement and operation of mills, lathes, and other cutting equipment in modern machining. This improves efficiency because the CNC machine operates without a human operator, lowering labour costs for machine shops.

1.1. *Turn-milling*

It is a sophisticated processing technique. It is capable of generating complex curved surfaces or special-shaped pieces using a rotating motion applied to both the cutting tool and the workpiece at the same time. Instead of employing traditional grinding methods, substantial research has been performed in the field of aviation manufacturing to make difficult-to-cut thin-walled workpieces. This study provides an overview of turn-milling technology based on existing research. The sorts of workpieces utilised in turn-milling were first summarised. The turn-milling mechanisation and cutting process were then investigated. Based on the turn-milling mechanisation and forming process, the research state of chip formation, cutting force, chatter stability, and surface quality was examined before making some suggestions and forecasts for future turn-milling research and applications. The findings of this review are valuable for future academics and research areas to acquire some insight into key foundations and references on turn-milling.

1.2. Equipment, cutting conditions and tools

Figures 1.1a and 1.1b demonstrate how PVD coated carbide inserts of ISO Grade S01 MP9005 and Ti-6Al-4V workpiece materials were machined on a CNC Turn-mill machine and an IR gun was used to record tool temperature and work-piece temperature. A MITUTOYO surface roughness tester was utilised to measure surface roughness parameters.

Fig 1 Ti6Al4V Work-piece Materials and PVD carbide inserts

Fig. 2. Turn-milling Machine

2. LITERATURE REVIEW

S.K. Choudhary (1): The objective of the present experimental work is to understand the phenomenon of orthogonal turn-milling especially in relation to the effects of work piece revolution, cutter diameter and depth of cut. Surface finish of the machined surface and the optimum work speed at which the surface roughness was minimum has been studied. It has been shown that surface quality obtained by turn-milling process is better than that of conventional milling process.

Alptunc comak, Yusuf Altintas (2): This paper presents the mechanics of turn-milling operations to predict cutting forces, torque and power requirements. The resulting feed vector is modeled as a function of linear velocities of the drives, and angular speeds of workpiece and tool spindles. The generalized chip thickness distribution is modeled as a function of linear feed drive motions, tool and workpiece spindle rotations. The identification of productive tool and workpiece spindle speeds is demonstrated using chip load limit of the tools and torque-power constraints of the turn milling machine tools.

J. kopac, M. pogacnic (3): Due to the complex kinematics of Turn-milling process the geometry of the tool and its position according to the workpiece is very important. Practical results enabled a comparison of the roughness between the centric and eccentric turn milling with different process parameters. At the same time the results demonstrated that vibrations have an enormously large influence on the quality of products.

Vedat Savas and Cetin Ozay (4): This paper presents an approach for optimization of cutting parameters at cylindrical work pieces leading to minimum surface roughness by using genetic algorithms in the tangential turn-milling process. During testing, the effects of the cutting parameters on the surface roughness were investigated.

Lida Zhu, Zenghui jiang (5): In this paper, an overview is given based on existing works on turn-milling technology. Firstly, workpiece types used in the turn-milling were summarized. After this, the turn-milling mechanization and cutting process were studied. The research status of the chip formation, cutting force, chatter stability, and surface quality was analyzed respectively based on the turn-milling mechanization and forming process before presenting some suggestions and predictions for future turn-milling research and applications. The results of this review are useful for gaining some insights on key foundations and references on turn-milling for future researchers and research areas.

Yiqiang wang, Richard c.m yam, Ming. J. Zuo (6): In the design and development of computerized numerical control lathes, an effective reliability allocation method is needed to allocate system level reliability requirements into subsystem and component levels. In this paper, we consider seven criteria for conducting reliability allocation. A comprehensive failure rate allocation method is proposed for conducting the task of reliability allocation. Example data from field studies are used to illustrate the proposed method.

3. PROCESS OF MACHINING

Taguchi design of experiments (DOE) was used to test Ti-6Al-4V workpieces under wet circumstances, with feed (f), spindle speed (N), and depth of cut (doc) as factors. Turn-milling was done on the CNC Turn-mill in wet conditions in this study. Surface roughness (Ra) and tool temperature (Tt) were measured with a surface roughness tester and a thermostat, respectively, while work-piece temperature (Tw) was predicted theoretically. The data were used to create a general linear model based on ANOVA to determine the significance and contribution of process characteristics. Signal-to-noise ratios (SN ratios) of the responses, on the other hand, were employed to determine the individual response optimality as well as a multi-response optimization technique such as Gray relational analysis.

Material

The most prevalent alloy is Grade 5, also known as T1-6A1-4V, Ti-6A1-4V, or Ti 6-4. It's made up of 6% aluminum, 4% vanadium, 0.25 percent (maximum) iron, 0.2 percent (maximum) oxygen, and the rest titanium. It has a great mix of strength, corrosion resistance, weldability, and fabricability. The titanium industry's workhorse alloy is this alpha-beta alloy. The alloy is fully treatable in sections up to 15mm and can withstand temperatures of up to 400°C (750°F). Because it is the most often used alloy (about 70% of all alloy grades melted are a sub-grade of Ti-6A1-4V), it has a wide range of applications in aircraft, airframe and engine components, maritime offshore, and power generation.

Experimental design

Taguchi DOE built experiments using the orthogonal array (OA) concept, with four levels for each of three process parameters (Spindle speed (N), feed (f), and depth of cut (doc), resulting in 16 (L16) experimental combinations as shown in Table. Equations 1-2 were used to calculate the signal-to-noise ratio, with the smaller-is-better concept applied to responses like surface roughness, tool temperature, and work-piece temperature, where little disturbance is required for a decent response signal.

$$(S/N)_{\text{Smaller-is-better}} = -10 * \log (\Sigma (Y^2)/n)$$

$$(S/N)_{\text{Larger-is-better}} = -10 * \log (\Sigma (1/Y^2)/n)$$

The Ti-6Al-4V work pieces are machined in wet circumstances with PVD carbide inserts using a set of experimental process parameters. Table 1 shows the answers that were generated, and Table 2 shows the calculated SN ratios (using Eq(s):1-2) for dry and wet situations, respectively. Thus, using Equations below the SN ratios are used to determine the individual optimality of the generated answers, as shown in Table 3.

$$\eta_{optimum} = \eta_{average} + \sum_{i=1}^{n} (\eta_{ideal} - \eta_{average})$$

$$\text{Response}_{\text{optimum}} = \sqrt{10 \pm \frac{\eta_{optimum}}{10}}$$

Where 'n' is observation number, 'ηopt' is optimum S/N ratio, 'ηavg' is average S/N ratio, 'ηideal'is ideal level of each S/N ratio parameter.

Table 1 Input parameters and output responses

Speed (rpm)	Feed (mm /rev)	DOC (mm)	Tool Temp (°C)	W/p Temp (°C)	Surface Roughness Ra
635	0.55	1.5	256	278	2.32
635	0.6	1.75	259	278	2.46
635	0.65	2	262	280	2.65
635	0.7	2.25	263	281	2.98
890	0.55	1.75	261	283	2.15
890	0.6	1.5	261	280	2.6
890	0.65	2.25	265	276	2.59
890	0.7	2	263	282	2.55
1144	0.55	2	266	280	2.07
1144	0.6	2.25	269	286	2.45
1144	0.65	1.5	260	279	2.51
1144	0.7	1.75	256	281	2.93
1400	0.55	2.25	267	283	2.96
1400	0.6	2	260	282	2.07
1400	0.65	1.75	256	277	2.11
1400	0.7	1.5	261	277	2.31

Table 2 SN ratios for the responses while Machining under wet conditions

Experiment no.	TT SN Ratio	WT SN Ratio	Ra SN Ratio
1	-48.165	-48.881	-7.310
2	-48.266	-48.881	-7.819
3	-48.366	-48.943	-8.465
4	-48.399	-48.974	-9.484
5	-48.333	-49.036	-6.649
6	-48.333	-48.943	-8.299
7	-48.465	-48.818	-8.266
8	-48.399	-49.005	-8.131
9	-48.498	-48.943	-6.319
10	-48.595	-49.127	-7.783
11	-48.299	-48.912	-7.993
12	-48.165	-48.974	-9.337
13	-48.530	-49.036	-5.845
14	-48.299	-49.005	-6.319
15	-48.165	-48.850	-6.486
16	-48.333	-48.850	-7.272
Average	-48.351	-48.949	-7.611
Opt.Value	256.8	277.4	2.07

Procedure:

Step 1: By normalising the SN ratios of all the responses (which have no similarity for comparison), the SN ratios of experimental data (which have no similarity for comparison) are changed to a sequence of comparable data:

Step 2: The deviation sequence of each response is calculated.

Step 3: Next, the sequence of comparable data from distinct responses is linked by assigning a weight age (distinguishable coefficient) that defines the grey relational coefficient as shown in equation-7:

Where min is the smallest value of the normalised values, max is the largest value of the normalised values, and is the distinguishing coefficient, which ranges from 0 to 1 and was previously considered to be 0.5 [5].

Larger normalised results correspond to better performance, according to Deng, and the best normalised result should equal

As a result, the grey relational coefficients [4-8] are derived, which indicate the relationship between the ideal (best) and actual experimental findings.

Step 4: The Grey Relational Grade is generated using the grey relational coefficients of all connected responses.

Based on the grey relationship grade, the rating must be supplied in descending order. Ideal process parameter combinations are those with the highest rank.

The GRA approach process was applied in both cases to determine the best mix of responses, as shown in Table 6.

Table 6 Grey Relational Coefficients in wet condition machining

Exp No.	Grey relation coefficient			Grey Relational Grade	Rank
	Ra	Tt	Tw	GRG	
1	0.33	1.00	1.00	0.772304	2
2	0.33	0.60	0.60	0.572797	10
3	0.33	0.43	0.43	0.448505	14

4	0.33	0.33	0.33	0.385802	16
5	0.43	1.00	0.60	0.623171	8
6	0.43	0.60	1.00	0.598804	9
7	0.43	0.43	0.33	0.509533	12
8	0.43	0.33	0.43	0.43169	15
9	0.60	1.00	0.43	0.633285	6
10	0.60	0.60	0.33	0.45151	13
11	0.60	0.43	1.00	0.625469	7
12	0.60	0.33	0.60	0.562831	11
13	1.00	1.00	0.33	0.686905	4
14	1.00	0.60	0.43	0.654124	5
15	1.00	0.43	0.60	0.772439	1
16	1.00	0.33	1.00	0.720818	3

4. EXPERIMENTATION DATA ANALYSIS

4.1. ANOVA

Analysis of variance (ANOVA) is a collection of statistical models that analyse the difference between group means of answers or SN ratios, as well as the variation within and between groups, by accepting or rejecting the null hypothesis. Until and unless the alternate hypothesis is proven to be right, it assumes the null hypothesis is correct.

The F-statistical values can be used to accept or reject the null hypothesis, for example, if F-statistic > F-critical, reject the null hypothesis.

It also determines and illustrates the impact of design factors to the response quality characteristic using an F-statistic test with a 95 percent significant level (i.e., 0.05 probabilities. Table 5 shows the results of the ANOVA on the SN ratios of the reactions in dry and wet situations.

Table 7 ANOVA of SN ratios of Responses for Tool Temperature

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution	Remarks
Speed (rpm)	3	31.687	10.562	8.59	0.014	22%	Significant
Feed (mm/rev)	3	1.687	0.5625	0.46	0.722	1%	Not Significant
DOC (mm)	3	103.18	34.395	27.98	0.001	71.68 %	Highly Significant
Error	6	7.375	1.2292				

Table 8 Analysis of Variance of SN Ratios of Responses For Work-Piece Temperature

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution	Remarks
Speed (RPM)	3	25.250	8.4167	12.62	0.005	24%	Significant
Feed (mm/rev)	3	5.250	1.7500	2.36	0.145	5%	Significant
DOC (mm)	3	73.250	24.416	36.63	0.000	68%	Highly significant
Error	6	4.000	0.6667				

Table 9 Analysis of Variance of SN Ratios of Responses For Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	contribution	Remarks
Speed (rpm)	3	0.5178	0.1726	10.01	0.009	39%	Significant
Feed (mm/rev)	3	0.6733	0.2244	13.02	0.005	50%	Highly Significant
DOC (mm)	3	0.0434	0.0144	0.84	0.520	3%	Not Significant
Error	6	0.1034	0.0172				

5. CONCLUSION

Turn Milling Operations have been done on Ti alloy work-pieces using PVD tool bit. Based on Taguchi DOE, 16 operations have been performed with different sets of process parameters.

By using GRA Technique optimum set of process parameters is found whose values of speed, depth of cut and feed respectively are 1400 rpm, 0.65mm and 1.75 mm/rev.

Taguchi Optimisation process is performed for individual parameters and following results were obtained:

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Table 10 Taguchi Optimisation Analysis

T_T (°C)	T_W (°C)	R_a (µm)
256.8	277.4	2.07

1)At speed 1400 rpm, feed rate of 0.65 mm/rev and depth of cut of 1.75 mm we have an optimal tool temperature of 256.8°C.

2) At speed 1400 rpm, feed rate of 0.65 mm/rev and depth of cut of 1.75 mm we have an optimal work-piece temperature of 277.4°C.

3) At speed 1400 rpm, feed rate of 0.65 mm/rev and depth of cut of 1.75 mm we have an optimal Surface Roughness of 2.07μm.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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