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Determination Of Effect Of Cutting Parameters On Tool Wear And Chip-Tool Interface Temperature In Turning Of Titanium Grade 2

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***Abstract*— Now-a-days increasing the productivity and the quality of the machined parts are the main challenges of metal cutting industry during turning processes. Optimization methods in turning processes, considered being a vital role for continual improvement of output quality in product and processes include modeling of input-output and in process parameters relationship and determination of optimal cutting conditions. This paper presents determination of effect of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of Titanium Grade 2 to achieve minimum tool wear, low Chip-Tool interface temperature. The experimental layout was designed based on the Taguchi's L9 (3^3) Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameter influencing the tool wear. The minimum tool wear was found at cutting speed of 55 m/min, depth of cut of 0.5 mm and feed of 0.35 mm/rev. Similarly low Chip-Tool interface temperature was obtained at cutting speed of 55 m/min, depth of cut of 0.5 mm and feed of 0.35 mm/rev. Finally, the relationship between factors and the performance measures were developed by using multiple regression analysis.**

Keywords—Turning of Titanium Grade 2, Tool wear, Chip-Tool interface temperature, Taguchi method, ANOVA, Regression Analysis.

I. INTRODUCTION

Aspects such as tool life and wear, surface finish, cutting forces, material removal rate, power consumption, cutting temperature (on tool and workpiece's surface) decide the productivity, product quality, overall economy in manufacturing by machining and quality of machining. During machining, the consumed power is largely converted into heat resulting high cutting temperature near the cutting edge of the tool. The amount of heat generated varies with the type of material being machined and machining parameters especially cutting speed, which had the most influence on the temperature (Hamdan et al., 2012) [1]. Many of the economic and technical problems of machining are caused directly or indirectly by this heating action. Excessive temperatures directly influence the temperatures of importance to tool wear on the tool face and tool flank and inducing thermal damage to the machined surface (Shaw, 2005) [2]. All these difficulties lead to high tool wear, low material removal rate (MRR) and poor surface finish (Rahman et al., 1997) [3]. In actual practice, there are many factors which affect these performance measures, i.e. tool variables (tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle, etc.), workpiece variables (material, hardness, other mechanical properties, etc.) and cutting conditions (cutting speed, feed, depth of cut and cutting fluids). Many papers has been published in experimental based to study the effect of cutting parameters on surface roughness (Khidhir and Mohamed, 2011; Hardeep Singh et al., 2011) [4], tool wear (Haron et al., 2001) [5], machinability (Jaharah et al., 2009) [6], cutting forces (Lalwani et al., 2008) [7], power consumption (Bhattacharya et al., 2009) [8], material removal rate (Kaladhar et al., 2012) [9]. So it is necessary to select the most appropriate machining settings in order to improve cutting efficiency. Generally, this optimum parameter selection is determined by the operator's experience knowledge or the design data book which leads to decrease in productivity due to sub-optimal use of machining capability this causes high manufacturing cost and low product quality (Aggarwal and Singh, 2005; Yang and Tarng, 1998) [10].

Hence statistical design of experiments (DOE) and statistical/mathematical model are used quite extensively. Statistical design of experiment refers to the process of planning the experimental so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusion (Montgomery, 1997) [11]. J. Paulo Davim and Luis Figueira(2007) were investigated the machinability evaluation in hard turning of cold work steel (D2) with ceramic tools using statistical techniques [12]. It was concluded that the tool wear was highly influenced by the cutting velocity, and in a smaller degree, by cutting time. The specific cutting pressure was also strongly influenced by the feed rate.

Bhattacharya et al., (2009) have investigated the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. The result showed a significant effect of cutting speed on surface roughness and power consumption, while the other parameters have not substantially affected the response [8].

The aim of this experimental investigation is to the effect of the cutting parameters on tool wear and Chip-Tool interface temperature in turning of Titanium grade 2 workpiece by employing Taguchi's orthogonal array design and Analysis of Variance (ANOVA) under dry environment.

II. METHODOLOGY USED

A. Taguchi method

The Taguchi experimental design method is a well-known, unique and powerful technique for product or process quality improvement (Roy, 1999) [15]. It is widely used for analysis of experiment and product or process optimization. Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner's work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the nature of variation and the economic consequences of quality engineering in the world of manufacturing.

Taguchi introduces his concepts to:

- Quality should be designed into a product and not inspected into it.
- Quality is best achieved by minimizing the deviation from a target.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi recommends a three-stage process to achieve desirable product quality by design-system design, parameter design and tolerance design. While system design helps to identify working levels of the design parameters, parameter design seeks to determine parameter levels that provide the best performance of the product or process under study. The optimum condition is selected so that the influence of uncontrollable factors causes minimum variation to system performance. Orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design. Tolerance design is a step to fine-tune the results of parameter design (Ross, 1996) [14].

The statistical analysis of the data was performed by analysis of variance (ANOVA) to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

III. EXPERIMENTAL DETAILS

A. Work material

The work piece material selected for the study was Titanium Grade 2. It has high strength, high quality surface finish, high corrosion resistances and excellent biocompatibility. The size of the workpiece was 25mm diameter and 300 mm length. The chemical compositions and mechanical properties of workpiece materials are given in Tables 1and 2.

TABLE 1. CHEMICAL COMPOSITION OF TITANIUM GRADE 2 WORKPIECE IN PERCENTAGE BY WEIGHT

N	C	Fe	Ti
0.0560	0.0590	0.1660	99.1000

TABLE 2. MECHANICAL PROPERTIES OF TITANIUM GRADE 2

Mechanical Properties	Density (g/cc)	Hardness, Brinell	Tensile Strength, Ultimate (MPa)	Modulus of Elasticity (Gpa)	Thermal Conductivity (W/m-K)
	4.51	200	344	103	16.4

B. Selection of cutting tool and tool holder

In tests, High Speed Steel of ISO designation CNMG 120408 (80^0 diamond shaped inset) without chip breaker geometry has been used for experimentation. The cutting inserts were clamped onto a right hand tool holder having ISO designation PCLNR 2525 M12.

C. Experimental plan

The turning tests on the workpiece were conducted under dry conditions on a CNC lathe (JOBBER XL, ACE India) which have a maximum spindle speed of 3500 rpm and maximum power of 16 kW. A hole was drilled on the face of work piece to allow it to be supported at the tailstock (Fig. 1). Prior to actual machining, the rust layers were removed by a new cutting insert in order to minimize any effect of in homogeneity on the experimental results.

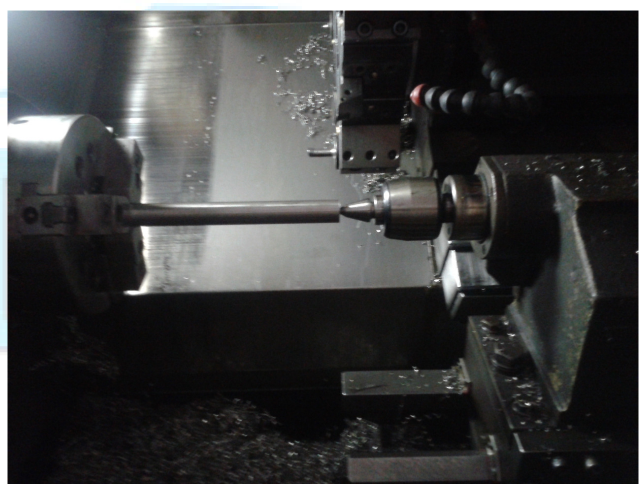

Fig. 1 View of cutting zone

D. Measurement of Chip-Tool interface temperature and Tool wear

The Chip-Tool interface temperature of the machined samples were measured by the use of infrared thermometer (make: HTC MTX-2) having temperature range of -30^0C to 550^0C and with optical resolution of 10:1.

During the course of experimentation the tool flank wear of worn out inserts were measured with the help of a profile projector (make: Nikon V-12B) having magnification in the range of 5-500X. Every experiment finished by constant length (100mm) to measure tool wear.

E. Design Of Experiment

The aim of the experiments was to analyse the effect of cutting parameters on the tool wear and Chip-Tool interface temperature of Titanium Grade 2. The experiments were planned using Taguchi's orthogonal array in the design of experiments which help in reducing the number of experiments. The experiments were conducted according to a three level, L9 (3^3) orthogonal array. The cutting parameters identified were cutting speed, depth of cut and feed. The control parameters and the levels used in experiment, experimental set up and results are given in the Tables 3 and 4.

TABLE 3. PROCESS PARAMETERS AND THEIR LEVELS

Parameters	Units	L1	L2	L3
Cutting Speed (V)	m/min	45	60	75
Feed Rate (F)	mm/rev	0.25	0.30	0.35
Depth of Cut (D)	mm	0.5	0.75	1.0

TABLE 4. ORTHOGONAL ARRAY L9 OF TAGUCHI EXPERIMENT DESIGN

Run No.	V	D	F	TW (mm)	T (°C)
1	55	0.5	0.25	0.10	94.8
2	55	0.75	0.30	0.26	110.3
3	55	1.0	0.35	0.18	124.5
4	75	0.5	0.30	0.17	138.5
5	75	0.75	0.35	0.35	147.5
6	75	1.0	0.25	0.39	156.0
7	95	0.5	0.35	0.18	174.0
8	95	0.75	0.25	0.41	181.4
9	95	1.0	0.30	0.37	200.0

IV. RESULTS AND DISCUSSIONS

A. Analysis of variance (ANOVA)

The experimental results from Table 4 were analyzed with analysis of variance (ANOVA), which used for identifying the factors significantly affecting the performance measures. The results of the ANOVA with the tool wear and workpiece surface temperature are shown in Tables 5 and 6 respectively. This analysis was carried out for significance level of α=0.1 i.e. for a confidence level of 90%. The sources with a P-value less than 0.1 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

TABLE 5. ANALYSIS OF VARIANCE FOR TOOL WEAR

Source	DOF	SS	MS	F	P	C (%)
V	2	0.035089	0.017544	36.72	0.027	33.24
D	2	0.063489	0.031744	66.44	0.015	60.15
F	2	0.006022	0.003011	6.30	0.137	5.70
Error	2	0.000956	0.000478			0.91
Total	8	0.105556				100
S = 0.0218581		R-sq = 99.09%		R-sq(adj) = 96.38%		

TABLE 6. ANALYSIS OF VARIANCE FOR WORKPIECE SURFACE TEMPERATURE

Source	DOF	SS	MS	F	P	C (%)
V	2	8497.7	4248.8	3032.47	0.000	89.91
D	2	897.9	449.0	320.44	0.003	9.5
F	2	52.6	26.3	18.79	0.051	0.56
Error	2	2.8	1.4			0.03
Total	8					100
S = 1.18369		R-sq = 99.97%		R-sq(adj) = 99.88%		

B. Main effect plots

The data was further analyzed to study the interact on amount cutting parameters (V, D, F) and the main effect plots on tool wear and Chip-Tool interface temperature were analyzed with the help of software package MINITAB16 and shown in Fig. 2 and 3 respectively. The plots show the variation of individual response with the three parameters; cutting speed, depth of cut and feed separately. In the plots, the x-axis indicates the value of each process parameters at three level and y-axis the response value. The main effect plots are used to determine the optimal design conditions to obtain the low tool wear and low Chip-Tool interface temperature.

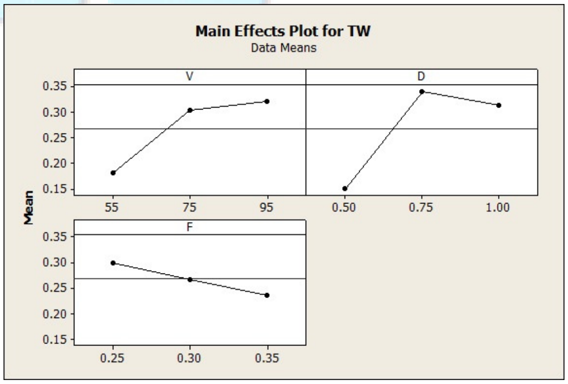

Fig. 2 Main effects plot for tool wear (TW)

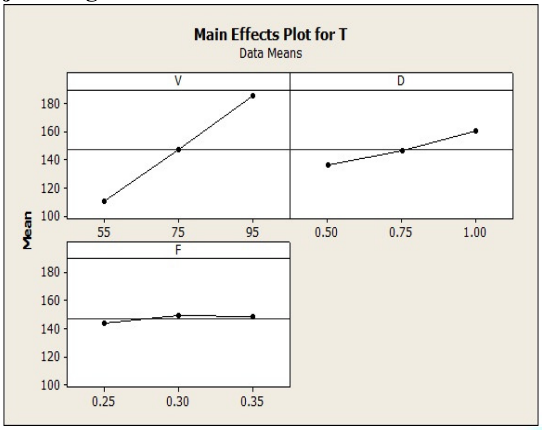

Fig. 3 Main effects plot for Chip-Tool interface temperature (T)

Fig. 2 shows the main effect plot for tool wear (TW). The results show that with the increase in cutting speed there is a continuous increase in tool wear. On the other hand, as the feed increases the tool wear decreases. However, with the increase in depth of cut there is an increase in tool wear up to 0.75 mm. A depth of cut of 0.75 mm produces a highest tool wear and 0.5 mm show the lowest tool wear. Based on analysis using Fig. 2 low value of tool wear was obtained at cutting speed of 55 m/min (level-1), DOC of 0.5 mm (level-1) and feed of 0.35 mm/rev (level-3). For comparison, the main effects plot for Chip-Tool interface temperature Fig. 3 shows that same levels of cutting parameters (V: 55 m/min, D: 0.5 mm and F: 0.35 mm/rev) produce lower Chip-Tool interface temperature (T). Thus, the lower Chip-Tool interface temperature gives less tool wear on the cutting tools.

C. Regression equations

The relationship between the factors (cutting speed, depth of cut and feed) and the performance measures (tool wear and Chip-Tool interface temperature) were modeled by multiple linear regression. The following equations are the final regression models in terms of coded parameters for:

Tool wear (TW):

$$TW= - 0.050 + 0.00350\ V + 0.327\ D - 0.633\ F$$

(R=0.85)

Chip-Tool interface temperature (T):

$$T = - 44.1 + 1.88\ V + 48.8\ D + 46.0\ F$$

(R=0.80)

V. CONCLUSIONS

1. The experimental results showed that the Taguchi parameter design is an effective way of determining the optimal cutting parameters for achieving low tool wear and low Chip-Tool interface temperature.

2. The percent contributions of depth of cut (60.85%) and cutting speed (33.24%) in affecting the variation of tool wear are significantly larger as compared to the contribution of the feed (5.70%).

3. The significant parameters for Chip-Tool interface temperature were cutting speed and depth of cut with contribution of 89.91% and 9.5% respectively. Although not statistically significant, the feed has a physical influence explaining 0.56% of the total variation.

5. The relationship between cutting parameters (cutting speed, depth of cut, feed) and the performance measures (tool wear and Chip-Tool interface temperature) are expressed by multiple regression equations which can be used to estimate the expressed values of the performance level for any parameter levels.

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