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TAGUCHI APPROACH FOR SURFACE ROUGHNESS OPTIMIZATION IN ULTRASONIC MACHINING OF TITANIUM AND ITS ALLOYS

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ABSTRACT

This study was aimed at carrying out research on ultrasonic machining (USM) of titanium (as work material) using different tool materials to know their impact on surface finish, and to model these characteristics for their application in manufacturing industry. In the current study the work has been limited to commercially pure titanium, (TITAN15,ASTM Gr.2) and titanium alloy, (TITAN31,ASTM Gr.5), as work material, in combination with six different tool materials (Stainless steel; High speed steel; High carbon steel; Titanium; Tungsten carbide; Diamond) for experimentation. The results showed that the response variable (surface finish) was strongly influenced by the control factors (input parameters) individually, as well as interactions among them is also significant.

Key words: surface finish; commercially pure titanium; titanium alloy; ultrasonic machining.

1. Introduction

Titanium and its alloys are alternative for many engineering applications due to their superior properties (such as chemical inertness, high strength and stiffness at elevated temperatures, high strength to weight ratio, corrosion resistance, and oxidation resistance). However these properties also make titanium and its alloys difficult to machine into a precise size and shape (Thoe et al. 1998, Singh and Khamba 2007). As a result, their widespread applications have been hindered by the high cost of machining with current technology (Benedict 1987). Therefore, there is a crucial need for reliable and cost-effective machining processes for titanium and its alloys (Singh and Khamba 2008).

For stationary USM, an approach to model the SR has been proposed and applied for titanium and its alloys. The model developed is mechanistic in the sense that this parameter can be observed experimentally from a few experiments for a particular material and then used in the prediction of SR over a wide range of process parameters. This has been demonstrated for titanium and its alloys, where very good predictions are obtained using an estimate of multi parameters. This model has been applied for predicting the SR for pure titanium, (TITAN15, ASTM Gr.2) and titanium alloy, (TITAN31, ASTM Gr.5). Relationships between SR and controllable machining parameters (tool material, slurry type, slurry concentration, grit size, slurry temperature, and power density) have been revealed.

Table 1 and 2 illustrates the chemical composition of pure titanium (ASTM Gr.2) and titanium alloy (ASTM Gr.5). The hardness of pure titanium work piece used was 201 HV and for titanium alloy was 341 HV at 5 kg. Load.

For this model, L18 orthogonal array of Taguchi design has been used to study the relationship between SR and the controllable machining parameters (Phadke 1989). These relationships agree well with the trends observed by experimental observations (Singh and Khamba 2006). The comparison with experimental results will also serve as further validation of the model.

Table 1: Chemical Analysis of Titanium pure ASTM Gr 2

C	H	N	O	Fe	Ti
0.006	0.0007	0.014	0.140	0.05	Bal

Table 2: Chemical Analysis Titanium alloy ASTM Gr 5

C	H	N	O	Al	V	Fe	Ti
0.019	0.0011	0.007	0.138	6.27	4.04	0.05	Bal

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There are five sections in this paper. Following introduction section, design of experiment section describes the design of experiments using Taguchi technique. In third section, the results have been presented and discussed. Conclusions are drawn up in the fourth section followed by references.

2. Design Of Experiments

2.1 Description of USM process

The USM machine tool used for study was of 500W capacity, which consists of an ultrasonic spindle kit; a constant pressure feed system and slurry flow system. Figure 1 shows the schematic representation of stationary USM (Singh and Khamba 2004). The ultrasonic spindle kit comprises an ultrasonic spindle, mounted with cylindrical horn of 25.4 mm Ø, a power supply unit. The power supply converts 50 Hz electrical supply to high frequency 20 kHz AC output. This is fed to the piezoelectric transducer located in the spindle. The transducer converts the electrical input in to mechanical vibrations. The amplitude of vibrations is made fixed in range of 0.0253-0.0258 mm with a frequency of 20 kHz +/- 200 Hz. The static load for feed rate was fixed at 1.636 kg and slurry flow rate at 26.4 L/min. The replaceable tools used for machining were solid tools made by silver brazing; having same area of cross-section (5 mm Ø).

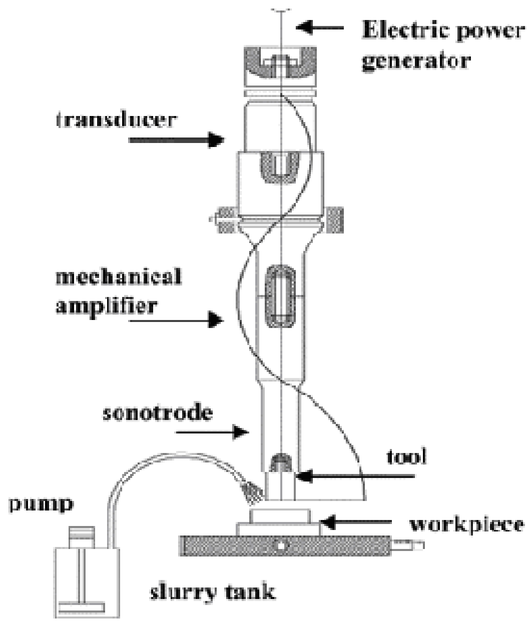

Fig 1: Schematic representation of the USM

Table 3 and table 4 shows different control variables with their levels and control log for experimentation respectively. For the temperature control of the slurry, three temperature ranges/ levels low (10°C), medium (27°C) and high (60°C) has been selected, based upon experimental limitations (Maintaining temperature of slurry at the tool tip). The levels of other parameters are based upon pilot experimentation.

Table3: Different control variables and their levels

S. No	Factor Name	L	L1	L2	L3	L4	L5	L6
A	Tool	6	SS	HSS	HCS	WC	Di	Ti
B	Slurry Conc.	3	15%	20%	25%			
C	Slurry Type	3	B_4C	Si_4C	Al_2O_3			
D	Slurry Temp.	3	10°C	27°C	60°C			
E	Power Rate	3	30%	60%	90%			
F	Slurry Grit	3	220	320	500			

Table 4: Control Log for experimentation based upon L18 orthogonal arrays (Taguchi Design)

Expt No.	**A**	**B**	**C**	**D**	**E**	**F**
1	SS	15%	B_4C	10ºC	30%	220
2	SS	20%	Si_4C	27ºC	60%	320
3	SS	25%	Al_2O_3	60ºC	90%	500

Expt No.	A	B	C	D	E	F
4	HSS	15 %	B_4C	27° C	60 %	500
5	HSS	20 %	Si_4C	60° C	90 %	220
6	HSS	25 %	Al_2O_3	10° C	30 %	320
7	HCS	15 %	Si_4C	10° C	90 %	320
8	HCS	20 %	Al_2O_3	27° C	30 %	500
9	HCS	25 %	B_4C	60° C	60 %	220
10	WC	15 %	Al_2O_3	60° C	60 %	320
11	WC	20 %	B_4C	10° C	90 %	500
12	WC	25 %	Si_4C	27° C	30 %	220
13	Di	15 %	Si_4C	60° C	30 %	500
14	Di	20 %	Al_2O_3	10° C	60 %	220
15	Di	25 %	B_4C	27° C	90 %	320
16	Ti	15 %	Al_2O_3	27° C	90 %	220
17	Ti	20 %	B_4C	60° C	30 %	320
18	Ti	25 %	Si_4C	10° C	60 %	500

2.2 Model for predicting SR in USM

The study presented in this paper has been based on macro-modeling concept. The step of building a mathematical model of system is bypassed. The concern is primarily with obtaining the optimum system configuration with minimum expenditure of experimental resources. The P-diagram (Process Diagram) for the process is shown in figure 2. The titanium and its alloys machining is viewed as “black box”. The parameters that influence the output are identified and divided in to two classes: Noise factors and Control Factors. The best settings of control factors are determined through experiments. For the analysis *rd Expert* ™ software has been used. The robust design method lends itself well for optimization through the macro modeling approach. Following output parameter has been studied as response variables for analysis.

Name: Surface Roughness
Type: Nominal the Best (Ideal Function)
Response: S.R. (microns)

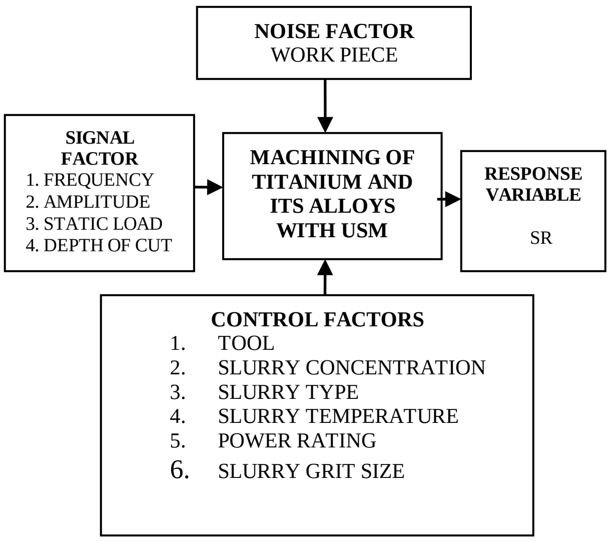

Fig 2: P-Diagram for USM of Titanium alloys

3. Results

Table5 shows the test data summary and table6 shows the factor effect of each input parameter. Figure3 represents S.R. Signal to noise ration (S/N) Vs different input parameters and table7 shows the F-test values and %age sum of squares. The ideal function selected here is nominal the best type. Figure4 represents S.R. SEN Vs different input parameters and table8 shows the F-test values and %age sum of squares for S.R response. For S.R. slurry temperature is most important followed by slurry concentration and type of tool. Best settings were obtained at 27•C at 25% concentration with S.S tool. The selection of temperature and concentration setting may be explained on the basis that at this temperature and concentration neither sticking (because of freezing of slurry) nor evaporation took place, resulting in to maximum number of abrasive particles contributing in material removal mechanisms. The choice of SS tool is because of selection of ideal function as nominal the best type. Figure 5-6 represents Pie chart to understand %age contribution of each factor effect for S.R.

Table 5: Test Data Summary

S.No	Surface Roughness S/N	Surface Roughness SEN
1	16.06	-5.01
2	16.10	-7.85
3	23.39	-6.50
4	19.02	-2.25
5	7.73	0.75
6	14.88	-5.33
7	8.01	-6.23
8	16.51	-8.37
9	13.68	-1.92
10	9.73	-3.28
11	12.11	-3.99
12	20.24	1.63
13	11.50	-3.41
14	4.94	-6.08
15	15.84	-2.14
16	30.39	-0.71
17	4.99	-2.31
18	16.27	-6.59
Average	14.52	-3.86
Std Dev	6.45	2.85
Maximum	30.39	1.63
Minimum	4.94	-8.37

Table 6: Factor Effects

Factor	Level	Surface Roughness S/N
A) Tool	A1) SS	18.51
	A2) HSS	13.88
	A3) HCS	12.73
	A4) WC	14.03
	A5) Di	10.76
	A6) Ti	17.22
B)Slurry Concentration	B1) 15 %	15.79
	B2) 20 %	10.40
	B3) 25 %	17.38
C) Slurry Type	C1) B_4C	13.62
	C2) Si_4C	13.31
	C3) Al_2O_3	16.64
D) Slurry Temperature	D1) 10ºC	12.04
	D2) 27ºC	19.68
	D3) 60ºC	11.84
E) Power Rating	E1) 30 %	14.03
	E2) 60 %	13.29
	E3) 90 %	16.24
F) Slurry grit size	F1) 220	15.51
	F2) 320	11.59
	F3) 500	16.47
Average		14.52
Error Variance		16.72

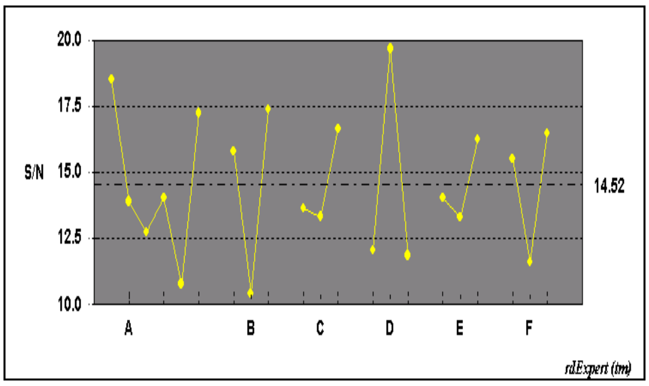

Fig 3: S/N response of S.R. Vs input parameters

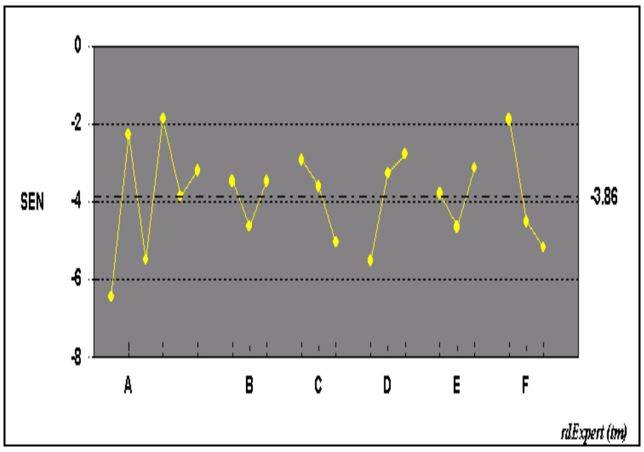

Fig4: SEN response of S.R. Vs input parameters

Table 7: F-test values and %age sum of squares (S/N)

F Value	1.5	4.8	1.2	7.2	0.8	2.4
%SS	17.5	22.8	5.8	33.9	4.0	11.3

Table 8: F-test values and %age sum of squares (SEN)

F Value	27.8	7.7	19.7	36.9	10.0	51.9
%SS	35.4	3.9	10.0	18.7	5.1	26.4

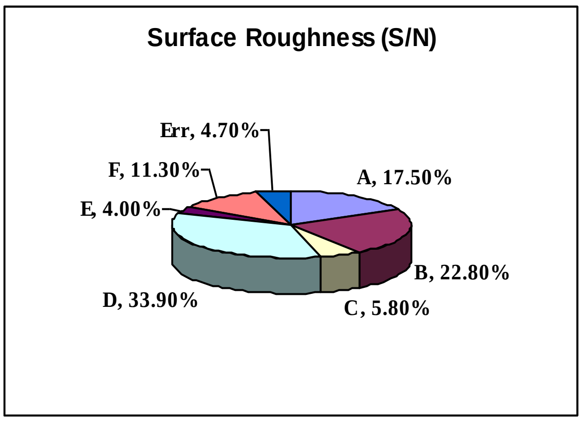

Fig5: Pie chart for surface roughness (S/N)

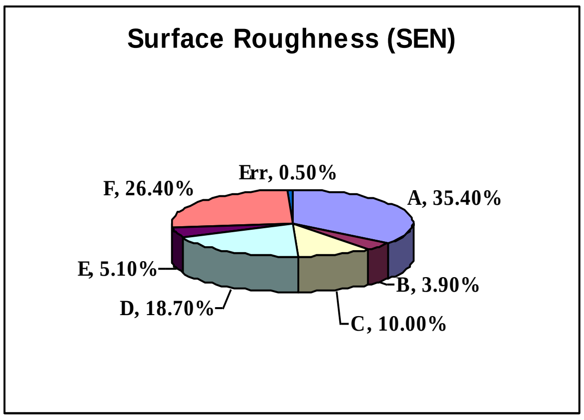

Fig6: Pie chart for surface roughness (SEN)

For S.R the most significant factor is slurry temperature with contribution of 33.9%, followed by slurry concentration with contribution of 22.8%. The third significant factor is type of tool with contribution of 17.5%. The remaining three input parameters namely slurry grit-size, slurry type and ultrasonic power rating are in-significant. The model developed shows close relationship between the experimental observations made otherwise. The present results are valid for 90-95% confidence interval.

The verification experiment reveals that on an average there was 21.7% improvement for the selected work piece (TITAN15 and TITAN31).

4. Conclusions

Following conclusion can been drawn from the present study.

As regards to SR in USM of titanium alloy is concerned, optimized results are obtained at 27•C at 25% concentration with S.S tool.

These results are valid within the specified range of the process parameters. In the present work, 500W piezoelectric transducer based USM apparatus was used. Secondly the depth of cut was limited as excessive length of the tool was adding to tool weight, and tool weight more than 50mg was resulting in auto-cut for machine. Hence results are limited in present form to machine comparatively small sized work pieces.

The use of solid tool leads to the problem of flushing of slurry particles from the machined surface after a certain depth of cut. Because of this reason, the depth of cut was limited to 1.0 mm in the present work. Also the fabrication of hollow tool was a constraint especially for diamond tool.

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Further maintaining slurry temperature below 10°C at tool-work interface was a problem in the present set up. So, experimentation below slurry temperature of 10°C was not done.

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