Machining Optimization of Nano Coated Tool Insert in Hard Turning using Taguchi Method

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***Abstract*—In this study, the Taguchi method is used to find the optimal cutting parameters in hard turning. The orthogonal array, the signal- to-noise ratio, and analysis of variance (ANOVA) are employed to study the performance characteristics in turning operation of AISI 52100 steel bar using Al4 in tungsten carbide tool insert. Three cutting parameters namely, Speed rate, Feed rate, and Depth of cut, are optimized with consideration of force and temperature. Optimal cutting parameters for each performance measure were obtained and the experimental results are provided to illustrate the effectiveness of this approach.**

Keywords—nano coated insert; hard turning; taguchi technique; speed; feed rate; depth of cut (DOC).

I. INTRODUCTION

The competitive race to make lighter, more efficient products that meets customer demands for greater energy efficiency is one of the factors driving the increased use of advanced materials in manufacturing. Whether the project involves use of high silicon aluminum alloys for thin walled automotive engine components or new lightweight materials to replace titanium in aircraft structures, design engineers across a spectrum of industries are specifying lighter non-ferrous materials and Nano coated material to increase the efficiency of their end products. These new materials include Nano coated aluminum-silicon alloys, metal matrix composites, carbon composites and glass fiber reinforced plastics. Their use in manufacturing presents a challenge for tool engineers because these materials can be extremely difficult to machine and create tremendous tool wear [2]. The tool wear can be attributed to both the abrasiveness of hard particles added to these materials for strength and chemical wear caused by corrosive acids created from the friction and heat during machining. To control wear problems, tool engineers have had to upgrade their tooling to the hardest tool materials, such as Nano coating [1]. Nano coated tool is an ideal tool material for machining abrasive non-ferrous metals and non-metal composites because it is one of the hardest known materials and it will it not be attacked by chemical wear when cutting non-ferrous materials. Today's existing most of the research is on miniature of the component. But there is no specific methodology or techniques to find the different parameter relationship for producing one such component. Here we take one such problem of Nano Coating in Carbide Inserts [5]. Simulation of Nano coated tool for different machining parameters for inserts is done using ANSYS thermal modeling. Here modeling of inserts is done in Pro-E and imported to ANSYS thermal Analysis. Here temperature is calculated for different feed and depth of cut with reference to various journals and Experimental data. This calculated data temperature is applied on inserts on ANSYS to find its performance related to different level of coating. Final results obtained for conclusion are temperature distribution and thermal gradient.

II. NANOTECHNOLOGY

First, Nanotech is the study of control of matter based on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller, and it involves in developing materials or devices within that size. Nanotechnology is very diverse, ranging from novel extensions of conventional physics. It completely has a new approaches based upon molecular structure to develop new materials with dimensions on the Nano scale.

III. HARD TURNING

Since the late 1970's the turning of material with hardness greater than 35HRC, has become economically, environmentally, and technically viable. Hard turning is a competitive finishing process for manufacturing precision mechanical components; the hard turning process is similar enough to conventional turning that the introduction of this process into the normal factory environment can happen with relatively small operational changes when the proper elements have been addressed. Hard turning is best accomplished with cutting inserts made from carbide inserts. Since hard turning is single point cutting, a significant benefit of this process is , it has the capability to produce contours and to generate complex forms with inherent motion capability of modern machine tools. High quality hard turning applications do require a properly configured machine tool and the appropriate tooling. For many applications, Carbide tooling will be the most dominant choice. However, ceramic [1] also have roles in this Process. The range of applications for hard turning varies widely, where in some cases hard turning serves as a grinding replacement process and can also be quite effective for pre-grinding preparation processes. The attractiveness of the process lies in the performance numbers.

The purpose of product or process development is to improve the performance characteristics of the product or process relative to customer needs and expectations. The purpose of experimentation should be to understand how to reduce and control variation of a product or process; subsequently, decisions must be made concerning which parameters affect the performance of a product or process. A matrix experiment consists of a set of experiments where the settings of several product or process parameters to be studied are changed from one experiment to another. Matrix experiments are also called design experiments, parameters are also called factors, and the parameter settings are also called levels. There are two methods in conducting experiments.

- Full factorial experimental design. (Design of experiments technique)
- Frictional factorial experimental design (Taguchi method)

In full factorial technique all possible combinations of the inputs will be included in experiment. But in Fractional factorial experimental design a smaller number of combinations is sufficient

IV. DESIGN OF EXPERIMENTS PROCESSD

The planning is the first phase involved in the design of experiments, when the factors and levels are selected and therefore is the most important stage. If the real influential factor and levels are selected the results will be positive. If not, the experiment will result as negative.

The planning phase involves the following steps.

- State the problems or areas of concern.
- Select the quality characteristics and measurements.
- Identify control and noise factor.
- Select the appropriate orthogonal array.
- Assign factors to OA and locate interactions.

Cutting forces has been one of the most important quality measures in many mechanical products. Thus an attempt is made to obtain an optimal setting of turning process parameters (cutting speed, feed rate, and depth of cut) resulting in an optimal value of surface finish when machining MARAGING STEEL with CARBIDE INSERTS.

A minimum of two levels are required to evaluate a factors effect on a giving quality characteristic. In the beginning round more number of factors can be included with reduced levels so that the size of the experiments will be minimized. After finding the influential factors through the first round, levels can be increased to optimize the response.

The selection of parameters of inserts was based on some preliminary experiments and from literature survey. The selected parameters with their levels are listed in table.

TABLE I. THE SELECTED PARAMETERS WITH THEIR LEVELS

Factors/parameters name	Level 1	Level 2	Level 3
Cutting speed (mm/min)	225	330	350
Feed (mm/rev)	0.05	0.075	0.1
Depth of cut (mm)	0.1	0.2	0.3

The following parameters were kept fixed during the entire experiment.

Work piece material	:	AISI 52100 Alloy Steel (En31)
Work piece condition	:	Hardened to 55HRC
Insert geometry	:	CCMT 21.51 Insert (2nano AL4)
Insert material	:	Tungsten Carbide
Cutting condition	:	Dry

V. SELECTION OF ORTHOGONAL ARRAY

Speed, feed rate and depth of cut are the parameters selected in this work. It was decided to study only the main effects. The number of levels used in the factors should be used to select either two level or three level types of OAs. The nonlinear relationship among the process parameters, if it exists, can only be revealed if more than two levels of the parameters are considered. Thus each selected parameters are considered. Thus each selected parameters was analyzed at three levels. Hence we have to select arrays from 3- level orthogonal arrays. It was decided to study only the main effects because the interactions are minimal interest. The total degrees of freedom (DOF) for three parameters, each at three levels, are six (Ross 1996). So, a three level OA with at least nine DOF has to be selected. The L9 OA (DOF=8) was thus selected for the present case study. The L9 OA is given in table below. This array specifies nine experimental runs and has four columns. Speed, feed, DOC are assigned to columns 1, 2, 3 respectively

TABLE II. TABLE ORTHOGONAL ARRAY FOR L9

Sl. No	Cutting Speed (mm/min)	Feed (mm/rev)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

VI. WORK MATERIAL PREPARATION

The work material is AISI 52100 Alloy Steel (En31). The different properties such as physical, mechanical thermal properties and composition of AISI 52100 Alloy Steel (En31) are given below.

A. *Physical Properties*

- Density : 7.83 – 8.08 g/cm3

B. *Mechanical Properties*

- Rockwell Hardness : 30.0 – 60.0
- Vicker's Hardness : 301 – 604
- Ultimate Tensile Strength : 840 – 2450 MPa
- Yield Tensile Strength : 655 – 2400 MPa
- Modulus Of Elasticity : 183 – 200 GPa
- Bulk Modulus : 140 GPa

- Poission Ratio : 0.30
- Shear Modulus : 70.0 – 77.0 GPa

C. Thermal Properties

- Thermal Conductivity : 17 – 27 W/mk
- CTE, Linear : 10 – 11.3 µm/m-^{o}

TYPE - AISI 52100 Alloy Steel (En31)

SIZE – 60 X 220 mm

SHAPE - Solid cylinder without interruptions

D. Heat Treatment

Before the heat treatment process, the work piece has to be pre-turned. This is done in order to eliminate the tapers in the work pieces. During pre-turning the diameter of the work piece was reduced from 62mm to 60mm. The heat treatment for the AISI 52100 work piece has been carried out using the gas carburizing furnace. The temperature should be maintained at 150 ^{0}C/Hr. After, soaking (holding) process was carried out. This is the process of holding the temperature at 840 ^{0}C. The holding time for our component was approximately 2 hours. After that oil quenching was done for one hour. The hardness of the work piece increases to an extent than the target hardness after this process. So in order to bring back the required hardness tempering is done 2 times in a tempering furnace. It took 2.5 hours and the temperature was 400 ^{0} C - 420 ^{0} C. Finally, air cooling is done. The final hardness is achieved was around 55 HRC.

VII. TOOL INSERT

Due to high resistance and easy Machinability for the hardened steel (AISI 52100), the tool material chosen for the study is Cubic Boron Nitride (CBN), The tool insert is Sandvik coromant TNGA 160404 S0 1030A 7015 with nose radius 0.4MM.PTFNR tool holder is used which provides 5^{0} side cutting-edge angle, 5^{0} end cutting –edge angle and -5^{0} back rake angle.

Fig. 1. Nano Coated CBN tool insert.

VIII. EXPERIMENTAL SETUP

Experiments are conducted on CNC lathe with different sets of machining conditions. The experiments were conducted in order to obtain the cutting forces and temperatures. For measuring cutting forces nine set of experiments were conducted as per DOE (Design of Experiments). The work material is fixed to the chuck and the job is centered. The insert is clamped to the tool holder and the necessary settings are made. The process parameters selected for the experiments are speed, feed and depth of cut. The turning operations are carried out with the Tungsten carbide insert which are specified earlier. The entire experiments are carried out in dry condition without using any coolant.

A. Experimental Design

According to the Taguchi's design an L9 orthogonal array is selected and nine combinations of experiments are performed for the selected levels of cutting parameters

TABLE III. CUTTING PARAMETERS AND THEIR LEVELS

Symbol	Cutting parameters	Levels		
		1	***2***	***3***
A	Cutting speed(mm/min)	225	330	350
B	Feed(mm/rev)	0.05	0.075	0.1
C	Depth of cut(mm)	0.1	0.2	0.3

B. Force Measuring Instruments

- Dynamometer
- Thermocouple

TABLE IV. RECORDED READING OBTAINED FROM MACHINING OPERATIONS

Orthogonal Array			Dynamometer Reading (N)	Thermocouple Reading (^{o}C)
Speed (mm/min)	**Feed (mm/rev)**	**Depth Of Cut (mm)**		
1	1	1	20.53	358
1	2	2	29.67	430
1	3	3	37.34	509
2	1	2	25.67	396
2	2	3	32.56	371
2	3	1	41.33	534
3	1	3	29.68	445
3	2	1	37.12	513
3	3	2	45.89	554

IX. VALIDATION AND RESULTS

The tool design is done in the modeling software, PRO-E which is used for the creation of the tool, and analysis is made by ANSYS software.

A. Tool Insert Design Using Pro-E

The tool insert was designed using PRO-E. The tungsten carbide tool insert which is two times nano-coated with Al4 of 0.001mm.

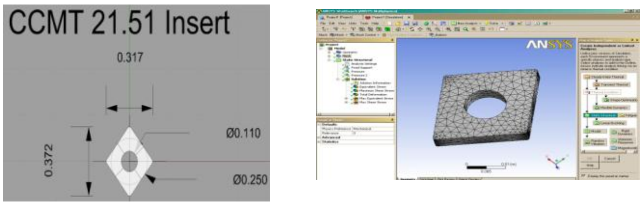

Fig. 2. Nano coated Al4 carbide insert with 0.001mm

B. ANSYS Results

ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions. Steady-state thermal analyses calculate the effects of steady thermal loads on a system or component. Users often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished. ANSYS can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time.

In our study, we have done the analysis using ANSYS and we have obtained the results in various stress and deformation.

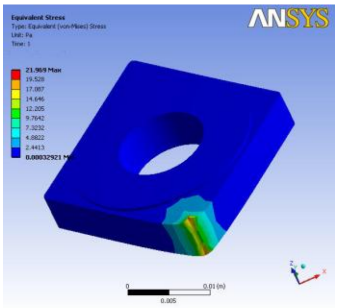

Fig. 3. Result of stresses in insert using ANSYS

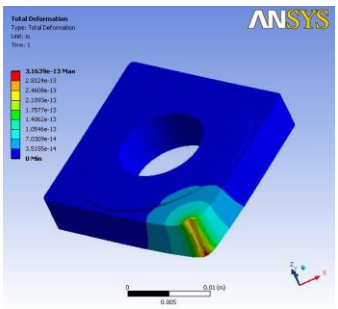

Fig. 4. Result of deformation in insert using ANSYS

TABLE V. DEFORMATION RESULT FROM ANSYS

Sl. No	Speed (mm/min)	Feed (mm/rev)	Depth of Cut (mm)	Load (N)	Deformation (mm)	
					Max	Min
1	1	1	1	20.53	3.16e-13	0
2	1	2	2	29.67	4.69e-13	0
3	1	3	3	37.34	5.91e-13	0
4	2	1	2	25.67	4.06e-13	0
5	2	2	3	32.56	4.15e-13	0
6	2	3	1	41.33	6.53e-13	0
7	3	1	3	29.68	4.70e-13	0
8	3	2	1	37.12	5.87e-13	0
9	3	3	2	45.89	7.26e-13	0

TABLE VI. STRESS RESULT FROM ANSYS

Sl. No	Speed (mm/min)	Feed (mm/rev)	Depth of Cut (mm)	Load (N)	Stress (N/mm^2)	
					Max	Min
1	1	1	1	20.53	21.96	3.16e-13
2	1	2	2	29.67	32.59	4.69e-13
3	1	3	3	37.34	41.01	5.91e-13
4	2	1	2	25.67	28.19	4.06e-13
5	2	2	3	32.56	35.76	4.15e-13
6	2	3	1	41.33	45.40	6.53e-13
7	3	1	3	29.68	32.60	4.70e-13
8	3	2	1	37.12	40.77	5.87e-13
9	3	3	2	45.89	50.40	7.26e-13

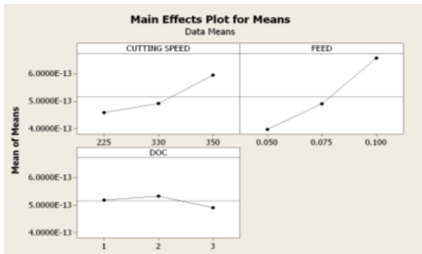

Fig. 5. Main Effect Plots For Means

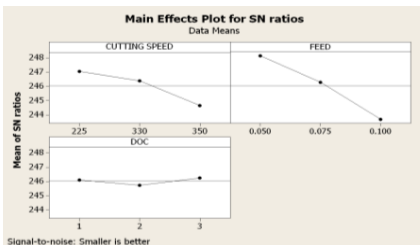

Fig. 6. Main Effect Plots For SN Ratio

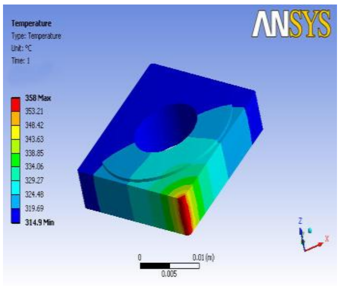

Fig. 7. Results of Temperature in Tool Insert Using ANSYS

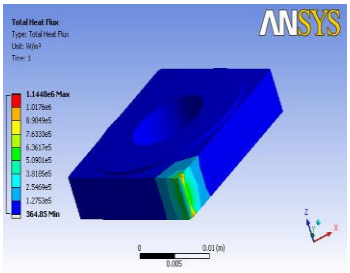

Fig. 8. Result of Heat Flux In Tool Insert Using ANSYS

TABLE VII. THERMAL DISTRIBUTION RESULTS FROM ANSYS

Sl. No	Speed (mm/min)	Feed (mm/rev)	Depth of Cut (mm)	Temp (°C)	Thermal Distribution (mm)	
					Max	Min
1	1	1	1	358	358	341.91
2	1	2	2	430	430	377.43
3	1	3	3	509	509	446.06
4	2	1	2	396	396	347.91
5	2	2	3	371	371	326.22
6	2	3	1	534	534	467.76
7	3	1	3	445	445	390.47
8	3	2	1	513	513	449.54
9	3	3	2	554	554	485.15

TABLE VIII.

TABLE IX. THERMAL GRADIENT RESULTS FROM ANSYS

Sl. No	Speed (mm/min)	Feed (mm/rev)	Depth of Cut (mm)	Temp (°C)	Thermal Gradient (W/m^2)	
					Max	Min
1	1	1	1	358	1.04e+06	364.8
2	1	2	2	430	1.40e+06	444.9
3	1	3	3	509	1.67e+06	532.8
4	2	1	2	396	1.28e+06	407.1
5	2	2	3	371	1.09e+06	379.3
6	2	3	1	534	1.76e+06	560.6
7	3	1	3	445	1.44e+06	461.3
8	3	2	1	513	1.68e+06	537.2
9	3	3	2	554	1.82e+06	582.8

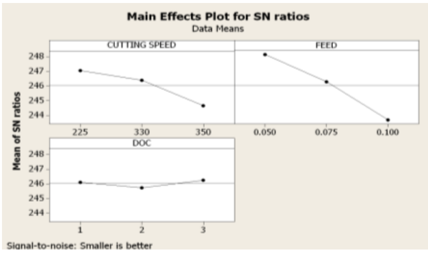

Fig. 9. Main effects plot for SN ratio

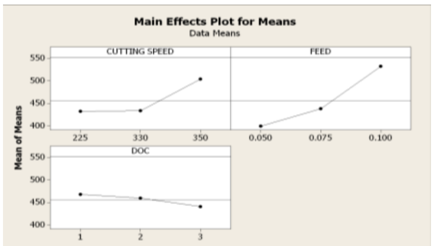

Fig. 10. Main effects plot for Means

C. ANOVA Table Results

The interaction graph is plotted using MINITAB-15, statistical software. From the main effects the slopes the line is reducing in order to feed, speed and depth of cut (DOC). When the cutting speed increase, the interfacial temperature decrease but for increasing in feed rate and depth of cut, temperature increases. When the feed rate increases, temperature increases with low cutting speed (100m/min) and decrease at high cutting speed (150m/min). When the DOC increases, the temperature increases at low DOC (.1mm) but for DOC (.3mm) temperature remains almost constant.

TABLE X. ANOVA TABLE RESULTS

Source	Sum Of Squares	DOF	Cutting Speed (mm/rpm)	F_{cal}	F_{tab}	P (%)
Speed	2752.69	2	1376.35	9.34	9	29.22
Feed	5362.18	2	2681.09	18.19	9	56.92
DOC	1010.71	2	505.35	3.43	9	10.73
Error	294.87	2	147.44			3.13
Total	9420.46	8	1177.56			100

X. CONCLUSIONS

In this study, the tool performance has been evaluated in terms of tool insert life, which is based on cutting speed, feed and depth of cut. Thus the Nano coated tool insert is optimized using Taguchi techniques. The optimum cutting levels found by this study are,

- Cutting speed = 225 mm/min
- Feed Rate = 0.05 mm/rev
- Depth of Cut = 0.3mm

The output obtained from the ANOVA table shows the cutting speed plays a dominant role in determining the tool performance in hard turning of AISI52100 steel.

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