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INVESTIGATION OF TOOL WEARS IN HIGH SPEED TURNING OF EN 31 STEEL

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Abstract:

Experiment is conducted on EN 31 alloy steel with carbide insert. Number of experiments and arrangement of process parameters are determined with the help of face centred central composite design. The input parameters are spindle speed, feed and depth of cut which is varied in three different levels. Response Surface Methodology is used to generate empirical relationship between the inputs and the responses which is validated by analysis of variance. The predicted values derived from Response Surface Methodology are compared with experimental data. Effects of input parameters on responses are analysed with the help of Response Surface Methodology. Multi-objective optimization of turning process parameters is done for Tool Wear.

Key Words: Tool Wears, Surface Methodology, EN 31 Alloy Steel, High Speed Turning & Optimization

Introduction to Various Machining Processes:

Machining is a metal removing process in which excess material is removed in the form of chip from raw material to get desired shape of the product as per the requirement. These processes have many common, controlled parameters for material removal and are collectively known as subtractive manufacturing [20].

The machining processes are classified in three ways

- ✓ Turning operations are operations that rotate the work piece as the primary method of moving metal against the cutting tool. The principal machining tool is lathe, used in turning.
- ✓ Milling operations are operations in which the cutting tool rotates to bring cutting edges to shear against the work piece. Milling machines are the principal machining tools used in milling operations.
- ✓ Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the work piece

High Speed Turning Operation:

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal [1] [8]. In this basic form, it can be defined as the machining of an external surface:

- ✓ With the work piece rotating.
- ✓ With a single point cutting tool, and
- ✓ With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even through a single point tool is specified, this does not exclude multiple tool setup, which are often employed in turning. In such setups, each tool operates independently as a single point cutter [22].

High speed turning is define as the process of single point cutting of part pieces that have hardness values over 45 Rc on a lathe or turning canter. Since surface roughness of R_{max}/R_z=1.6s can be achieved [3].

Figure 1: High Speed Turning

High speed turning applications are for parts that have roundness accuracy requirements between 0.5 and 12 microns, includes a variety of parts such as gears, injection pump components, hydraulic components, seat surfaces, and hard disk drive shafts [4] [25].

Process Parameters of High Speed Turning Operation:

Speed: Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (RPM), it tells their rotating speed. But the important feature for a particular turning operation is the surface speed or the speed at which the work piece material is moving past the cutting tool.

$$V = \pi DN/1000 \text{ m/min}$$

Where,

V = cutting speed,
D = Initial diameter of work piece (m),
N = Spindle speed (RPM)

Feed: Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power fed lathes the feed rate is directly related to spindle speed.

$$F = f\,N \text{ mm/min}$$

Where,

F = Feed,
F = Feed rate,
N = Spindle speed

Depth of Cut: It is the thickness of the layer being removed from the work piece or the distance from the uncut surface of the work to the cut surface.

$$\text{Depth of Cut (DOC)} = D_1\text{-}D_2/2$$

Where,

D_1 = Initial Diameter,
D_2 = Final Diameter

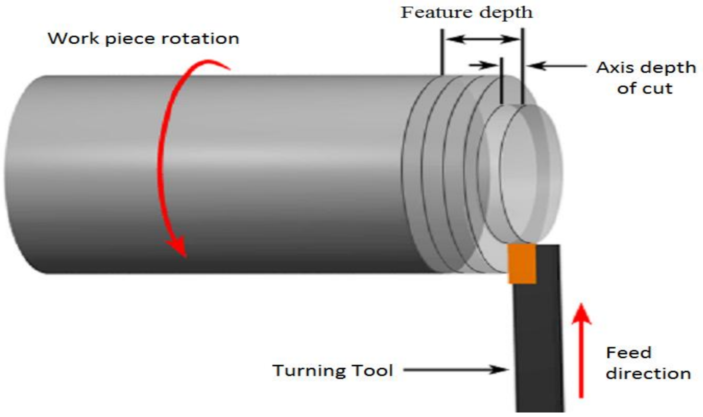

Figure 2: Turning operation

Cutting Tool Wear:

A phenomenon of great significance in metal cutting is tool wear. Many factors determine the type and rate at which wear occurs on the tool. The major critical variables that affect wear are tool temperature, type and hardness of tool material, grade and condition of work piece, abrasiveness of the micro constituents in the work piece material, tool geometry, feed, speed and cutting fluid. The type of wear pattern that develops depends on the relative role of these variables. Tool wear in machining in defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and the work piece. Specifically, tool wear is described by wear rate and is strongly determined by the temperature, stresses, and relative sliding velocity generated at the contact interface. Metal cutting tools are subjected to extremely arduous conditions; High surface loads and high surface temperature arise because the chip slides at the high speed along the tool rake face while exerting very high normal pressure and this face. The forces may be fluctuating due to the presence of hard particles in the component microstructure or more extremely, when interrupted cutting is being carried out [2]. Hence cutting tools need.

- ✓ Strength at elevated temperatures
- ✓ High toughness
- ✓ High wear resistance
- ✓ High hardness

Types of Tool Wear:

Flank Wear: Occurs on the tool flank as a result of friction between the machined surface of the work piece and the tool flank. Flank wear appears in the form of so called wear land and is measured by the width of this wear land, VB flank wear affects to the great extend the mechanics of cutting . Cutting forces increase significantly with flank wear. If the amount of flank wear exceeds some critical value (VB > 0.5- 0.6 mm), the excessive cutting force may cause tool failure [9].

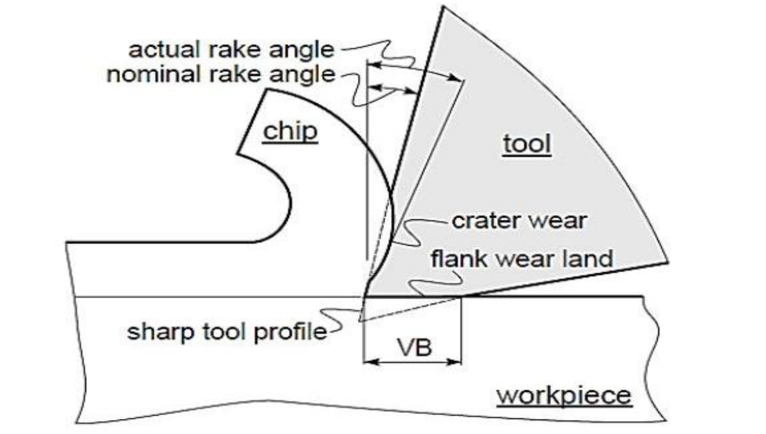

Figure 3: Flank wear

Notch Wear: This is a special type of combined flank and rake face wear which occurs adjacent to the point where the major cutting edge intersects the work surface. The gashing (or grooving, gouging) at the outer edge of the wear land is an indication of a hard or abrasive skin on the work material. Such a skin may develop during the first machine pass over a forging, casting a hot rolled work piece. It is also common in machining of material with high work hardening characteristics, including many stainless steels and heat resistance nickel or chromium alloy. In this case, the previous machining operation leaves a thin work hardening skin.

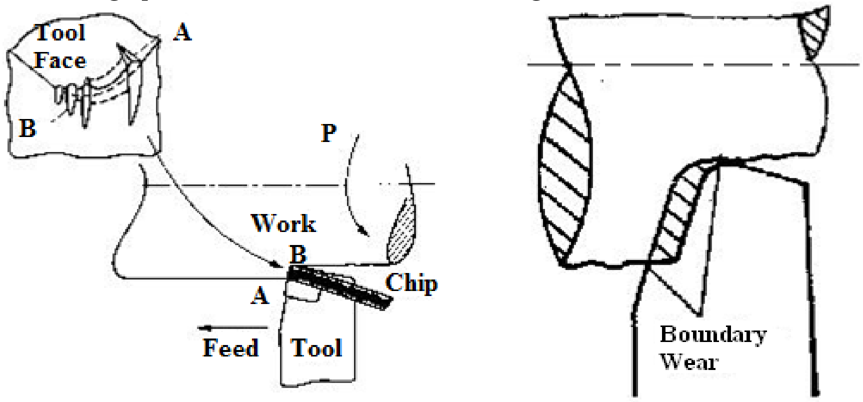

Figure 4: Notch Wear

Crater Wear: This type of wear occurs and when the tool surface is in contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure. Can be caused by spindle speed that is too low or a feed rate that is too high. In orthogonall cutting this typically occurs where the tool temperature is highest. Crater wear occurs approximately at a height equalling the cutting depth of the material.

K_M = Distance to middle
K_B = Width
K_T = Depth
K_L = Distance to start

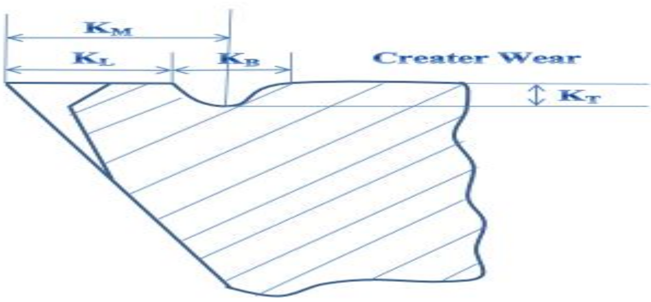

Figure 5: Crater wear

Ultimate Failure: The final result of tool wear is the complete removal of the cutting point ultimate failure of the tool. This may by temperature rise, which virtually causes the tool tip to soften until it flows plastically at very low shear stress. This melting process seems to start right at the cutting edge and because material flow blunts the edge, the melting process continues back in to the tool, within a few seconds a piece of tool almost as large as the engaged depth of cut is removed [6].

Different Stages of Tool Wear:

Initial (or Preliminary) Wear Region: This is caused by micro cracking, surface oxidation and carbon loss layer, as well as micro roughness at the cutting tool tip in tool grinding (manufacturing). For the new cutting edge, the small contact area and high contact pressure will result in high wear rate. The initial wear size is V_B = 0.05-0.1 mm normally.

Steady Wear Region: After the initial (or preliminary) wear (cutting edge rounding), the micro roughness is improved, in this region the wear size is proportional to the cutting time. The wear rate is relatively constant.

Severe Wear: When the wear size increases to a critical value, the surface roughness of the machined surface decreases, cutting force and temperature increase rapidly, and the wear rate increases. Then the tool loses its cutting ability. In practice, this region of wear should be avoided.

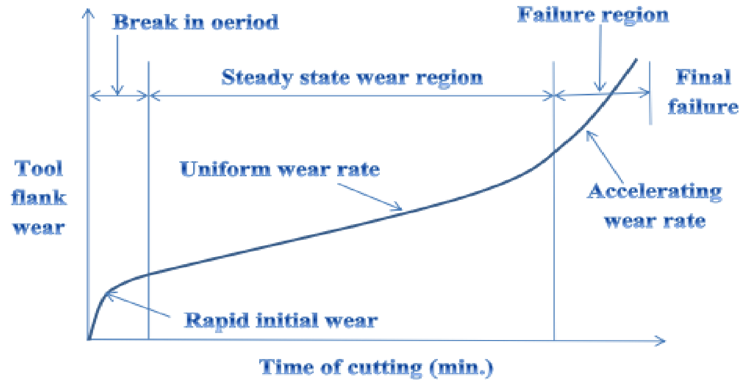

Figure 6: Different stages of wear

1. Literature Review:

W. B. Sai et al. [1] have shown that an increase in cutting speed causes a higher decrease of the time of the second gradual stage of the wear process. This has been due to the thin coat layer which has rapidly peeled off when high-speed turning. This investigation included the realization of a wear model in relation to time and to cutting speed.

Y. Huang et al. [2] have focused on the direct machining steel parts at a hardened state, known as hard turning have offered a number of potential benefits over traditional grinding in some applications. In addition, hard turning has several unique process characteristics, e.g., segmented chip formation and microstructural alterations at the machined surfaces, fundamentally different from conventional turning. Hard turning has been therefore, of a great interest to both the manufacturing industry and research community. Development of super hard materials such as polycrystalline cubic boron nitride (known as CBN) has been a key to enabling hard turning technology. Although various tool wear mechanisms, or a combination of several, coexist and dominate in CBN turning of hardened steels, it has been suggested that abrasion, adhesion (possibly complicated by tribochemical interactions), and diffusion may primarily govern the CBN tool wear in hard turning.

H. Chelladurai et al. [3] have shown that cutting tool wear has been a critical phenomenon which influences the quality of the machined part. In this paper, an attempt has been made to create artificial flank wear using the electrical discharge machining (EDM) process to emulate the actual or real flank wear. The tests were conducted using coated carbide inserts, with and without wear on EN-8 steel, and the acquired data were used to develop artificial neural networks model. Empirical models have been developed using analysis of variance (ANOVA). In order to analyze the response of the system, experiments were carried out for various cutting speeds, depths of cut and feed rates. To increase the confidence limit and reliability of the experimental data, full factorial experimental design (135 experiments) has been carried out. Vibration and strain data during the cutting process are recorded using two accelerometers and one strain gauge bridge. Power spectral analysis have been carried out to test the level of significance through regression analysis. Experimental results were analyzed with respect to various depths of cut, feed rates and cutting speeds.

M. U. Ghani et al. [4] have presented results of an investigation into the tool life and the tool wear behavior of low content CBN cutting tools used in hard turning of hardened H13 tool steel. The finite element method experiments involved measuring the cutting forces, cutting temperatures, tool wear, and the contact area. Using the measured cutting forces and the contact area in the orthogonal cutting model. The temperatures history from the analysis was matched with the experimental data have estimated the fraction of heat entering the tool for both conventional and high speeds. The heat partition into the tool was estimated to be around 21–22% for conventional speeds, whereas for high-speed turning, it was around 14%. The tool wear, however, was found to be dominated by chipping for both cutting speeds and could be reduced considerably by reducing the amount of heat entering the tool.

J. Xu et al. [5] have shown that in machining of AISI 1215 steel, tool wear has a close relation with the presence of manganese sulfide lubricant zone formed on the tool surface. In this work, with the aid of cutting temperature and tool Von Mises stress simulations, tool wear analysis on the uncoated and multi-layer (Al2O3/TiCN) coated carbide tools has been performed in high speed turning operation. Wear pattern and wear mechanisms were studied through the experimental results. The main findings have shown that the uncoated tool suffered high cutting temperature and severe tool wear and was not conducive to form a manganese sulfide lubricant zone in the turning operation. In contrast, the multi-layer coated tool could form a manganese sulfide lubricant zone on the chip–tool contact area. The beneficial roles of the manganese sulfide lubricant zone formed on the coated tool surface can be summarized as lubrication and diffusion blocking. The main wear mechanisms of the uncoated tool were crater wear, oxidation wear, adhesive wear, and abrasive wear, whereas for the multi-layer coated tool, they were crater wear, adhesive wear, and abrasive wear.

2. Mathematical Model of Tool Wear:

Problem Identification:

- ✓ After surveying above literature following problems has been identified.
- ✓ If a worn tool is not identified early enough, significant degradation of the work piece quality can occur.
- ✓ Some research has shown that an extension of wear, the allowed limit is accompanied by an increase in surface roughness.
- ✓ Ways and means of predicting or measuring wear have been the object of research for a long time, but experiments with newly developed tools in high-speed machining are very scarce.
- ✓ In any metal cutting operation, one of the major hurdles in realizing its complete automation is that of the cutting tool state prediction, where tool wear is a critical factor in productivity.
- ✓ With sensors based systems the most critical decision is prediction of cutting tool condition using signal response. In many cases wrong interpretation of the sensor signals by an operator leads to the wrong decision to switch off the machine tool which affects the quality of the product as well as production rate.
- ✓ Machining processes are non-linear and sophisticated in nature, and it is difficult to build a mathematical model, which requires suitable assumptions and may not be matching with real world metal cutting process.
- ✓ Direct methods of measuring tool wear have not been easily adaptable for shop floor application. They are not suitable for on-line condition monitoring system however they can be easily applied to off-line measurements and it consumes more time.
- ✓ A problem in TCM system is selection of proper sensor and its location. The sensors have to be placed as close as possible to the target location (close to the tool tip) being monitored.
- ✓ Cutting of hardened H13 tool steel should be performed under minimum quantity lubrication (MQL) conditions thus allowing some heat to be conducted into the cutting fluid.
- ✓ The tool experienced large crater wear and, after higher cutting passes, broke off completely from the edge due to highly localized plastic deformation.
- ✓ No distinct advantage in performing high speed turning of hardened H13 tool steel with CBN tool at high speeds.
- ✓ In hard turning, the cutting tool is subjected to maximum temperature and pressure near the nose. Therefore, the occurrences of higher pressure and/or temperature result in formation of flank wear. Minimum tool wear can be achieved when cutting speed is at low level of the experimental range.
- ✓ The cost of hard turning tools and the tool change down-time due to rapid tool wear impact the economic viability of precision hard turning.
- ✓ Rapid tool wear is one of the major hurdles affecting the wide implementation of hard turning in industry.

Mathematical Model of Tool Wear:

Design of optimal control for a machine tool necessitates a mathematical model of the machining process is view of the unfeasibility of carrying out all tests on the machine. A model for alloy steel turning with a carbide tool is developed accordingly; yielding the relation between the process parameters (cutting speed, feed and depth of cut) and tool wear (the unknown function in the performance index of the optimization). Results are analyzed and compared with those known form literature [25].

The general relationship of VB verses cutting time is shown in Fig.7 (so called wear curve). Although the wear curve shown is for flank wear, a similar relationship occurs for other wear types. From Figure 7 shows also how to define the tool life T for a given wear criterion W.

The slope of the wear curve (that is the intensity of the wear) depends on the same parameters, which effect the cutting temperature as the wear of cutting tool materials is a process extremely temperature dependent. Parameters, which affect the rate of tool wear, are

- ✓ Cutting conditions (cutting speed v, Feed f and depth of cut d)
- ✓ Cutting tool geometry (tool orthogonal rake angle)
- ✓ Property of tool material

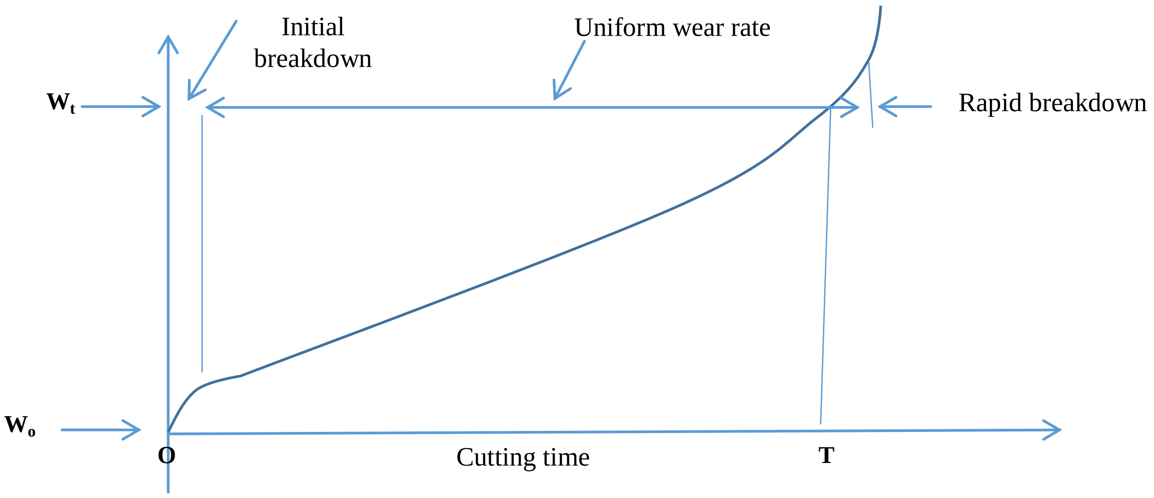

Figure 7: Development of flank wear with time for a carbide tool

From these parameters, cutting speed is the most important one. As cutting speed is increased, wear rate increase, so the same wear criterion is reached in less time, i.e, tool life decreases with cutting speed.

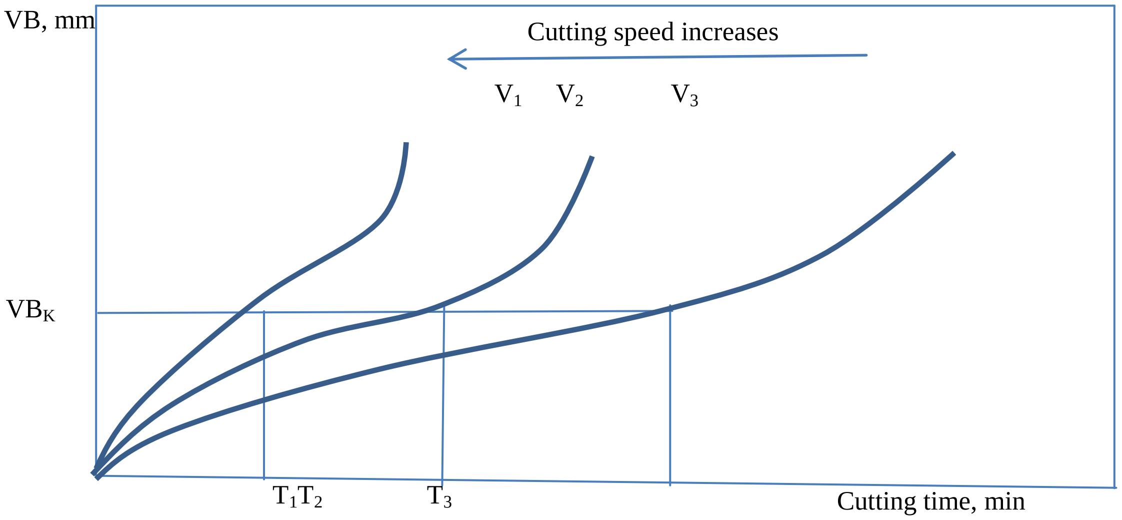

Figure 8: Effect of cutting speed with time

If the tool life values for the three wear curves are plotted on a natural log-log graph of cutting speed verses tool life as shown in the figure, the resulting relationship is a straight line expressed in equation from called the Taylor tool life equation. $V T^n = C$

Where n and C are constants, whose values depend on cutting conditions, work and tool material properties, and tool material properties, and tool geometry. These constant are well tabulated and easily available. An expanded version of Taylor equation can be formulated to include the effect of feed, depth of cut and even work material material properties. Taylor's tool life formula was modified to accommodate these changes as

$$V^cT^nf^ad^b = C$$

Where d is the depth of cut (mm) and f is the feed (mm/rev.) The exponents and a and b are to be determine experimentally for each combination of the cutting conditions. According to this information, the order of importance of the parameters is cutting speed, feed and depth of cut. Using these parameters, Equation below for the expanded Taylor tool life formula model can be rewritten as

$$T = C^{1/2} V^{-1/n} f^{1/n} d^{-1/n}$$

M.C shaw model gives the following relation

$$B_t = bw^2\tan\theta/2$$

Where, The volume worn away on the relief face (B_t) for a given wear land (w), depth of cut (b) and relief angle (θ).

3. Experimentation:

Selection of Work Piece: EN 31 alloy steel is selected as work piece material for the present work. EN31 High carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance.By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading.A good tool material should have all of the following characteristics

- ✓ Harder than the work it is cutting.
- ✓ High temperature stability.
- ✓ Resists wear and thermal shock.
- ✓ Impact resistant
- ✓ Chemically inert to the work material and cutting fluid

Select cutting tool insert and job material as CNMG120408 EN-TMR CTC1135 Carbide insert and EN 31 alloy steel respectively.Carbide tools are more expensive per unit than other typical tool materials, and it is more brittle, making it susceptible to chipping and breaking. To offset these problems, the carbide cutting tip itself is often in the form of a small insert for a larger tipped tool whose shank is made of another material, usually carbon tool steel. This gives the benefit of using carbide at the cutting interface without the high cost and brittleness of making the entire tool out of carbide. Its main use is in turning tool bits although it is very common in milling cutters and saw blades. Hardness up to about HRC 90. Sharp edges generally not recommended.

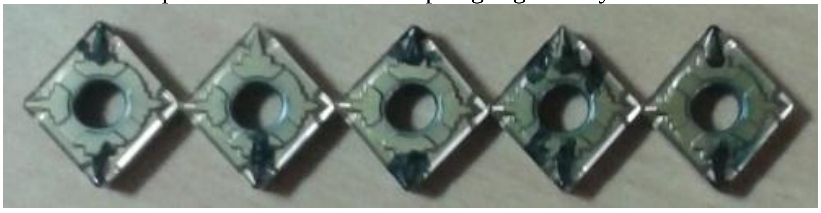

Figure 9: Carbide Insert Tool

Carbide Insert Specification:

Made- Taegu Tec (TT) Member IMC Group
Specification- CNMG 120408 EA TT5080

The EN 31 steel rod of size 120 mm and diameter 25 mm has been used for present work which is known for its high quality, High tensile strength usually supplied with machine able, giving good ductility, good shock resisting properties and good resistance to wear. The chemical composition and mechanical properties are given below in tabular form. EN 31 is usually supplied with a tensile strength of 750 N/ mm^2. EN 31 is a popular grade of through hardening alloy steel due to its excellent machinability. EN 31 can be further surface hardened to create components with enhanced wear resistance by induction or nit riding processing.

Table 1: Typical chemical composition of EN 31 steel

	C	Mn	Si	S	P	Cr
EN 31	**0.90-1.20**	**0.3-0.75**	**0.10-0.35**	**0.040**	**0.040**	**1.0-1.060**

Table 2: Mechanical properties ofEN 31 steel

Element	Objective
Tensile Strength	$750N/mm^2$
Yield Stress	$450N/mm^2$
Reduction of Area	45%
Elongation	30%
Modulus of elasticity	$215000N/mm^2$
Density	$7.8kg/m^3$
Hardness	63HRC

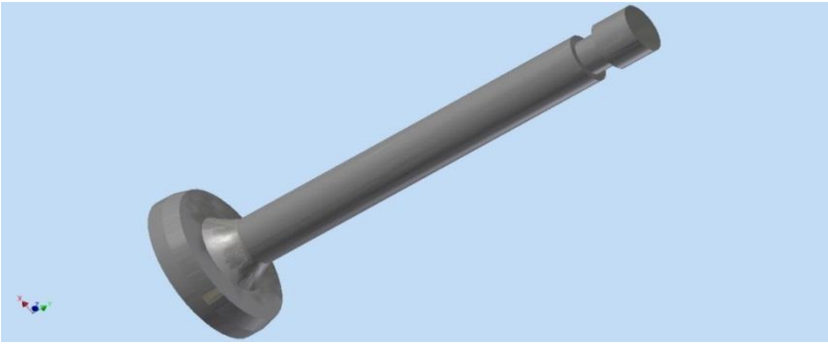

Figure 10: 3D Modelling of poppet valve

Figure 11: Work pieces after experimentation

Experimental Setup:

The EN 31 steel bar is held on the three jaw auto-centre pneumatic chuck on CNC turner. For machining, suitable CNC programming is used.

Figure 12: CNC Maxturn Plus

Table 3: Machine Specification

CAPACITY	
L x W x H	**1700x1400x2100 (mm)**
Weight	2500 kg
X-axis travel	120 mm
Z-axis travel	200 mm
Chuck size	135 mm
Max. turning diameter	200 mm
Max. turning length	200 mm
Swing over cross slide	130 mm
Swing over way covers	320 mm
Feed rate	0-10000 mm/min.
Rapid travers rate (X,Z)	10 m/min.
Spindle nose taper	A2/4
Spindle bore taper	MT4
Bore through spindle	41 mm
Maximum speed	6000 rpm
Turret	BTP63
Number of stations	8
Turning tool STD	20x20 mm
Total indexing for adjacent tool	0.35 sec
Boring bar size	32 mm

Process Variables and their Limits:

The working ranges of the parameters for subsequent design of experiment, based on there

Table 4: Process Variables and Their Limits

Variables/ Levels	-1	0	1
Depth of cut (mm)	0.08	0.18	0.28
Feed (mm/rev.)	0.07	0.12	0.17
Rotational speed (rpm)	900	1400	1900

To Measure Tool Wear:

Tool Wear Measurement:

Introduction:

- ✓ A toolmakers microscope is a measuring device that can be used to measure up to 1/1000th of an mm.
- ✓ It works on the principle of a screw gauge, but a few changes were added to it to make its operation easier.
- ✓ It needs application of optics too.
- ✓ A light focuses on the object and through lens we can object, which resembles the object.
- ✓ More clear shadow would be enhance the accuracy of measurement.

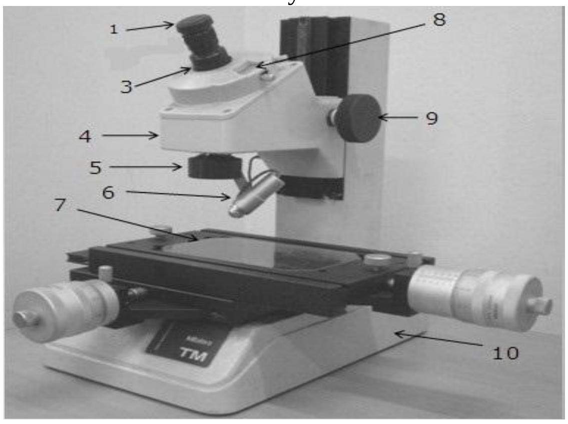

Figure 13: Tool makers' microscope

Specification:

- ✓ Eye Piece.
- ✓ Eye Piece Mount
- ✓ Optical Tube
- ✓ Objective
- ✓ Reflected Illuminator
- ✓ XY Stage
- ✓ Angle Dial
- ✓ Focusing Knob
- ✓ Power Panel

Collection of Data:

Table 5: Input and output of experiment

	Coded Data			Actual Data			Measured Response
S.No	**DOC (mm)**	**Feed Rate (mm/rev)**	**Speed Rate (RPM)**	**DOC (mm)**	**Feed (mm/rev)**	**Speed (RPM)**	**Tool Wear**
01	-1	1	-1	0.08	0.17	900	0.0004160
02	0	0	0	0.18	0.12	1400	0.0002175
03	0	0	0	0.18	0.12	1400	0.0002173
04	1	1	1	0.12	0.17	1900	0.0005218
05	0	0	0	0.18	0.12	1400	0.0002180
06	0	0	-1	0.08	0.12	1400	0.0002735
07	1	-1	1	0.12	0.07	1900	0.0002049
08	0	0	0	0.18	0.12	1400	0.0002172
09	-1	1	1	0.12	0.17	900	0.0002489
10	1	0	0	0.08	0.12	1900	0.0007529
11	-1	-1	1	0.12	0.07	900	0.0002135
12	1	-1	-1	0.08	0.07	1900	0.0004617
13	0	-1	0	0.18	0.07	1400	0.0000820
14	0	1	0	0.18	0.17	1400	0.0001495
15	-1	0	0	0.18	0.12	900	0.0005198

16	1	1	-1	0.08	0.17	1900	0.0008906
17	0	0	0	0.18	0.12	1400	0.0002172
18	-1	-1	-1	0.08	0.07	900	0.0002669
19	0	0	1	0.12	0.12	1400	0.0000619
20	0	0	0	0.18	0.12	1400	0.0002181

4. Results and Discussion:

Response Prediction for Tool Wear: In this study, an investigation is made for finding out optimum cutting parameters that speed; feed and depth of cut while the output parameters that are tool wear and surface roughness are kept minimum. EN 31 is selected as work piece material and coated carbide alloy is selected as cutting tool.20 nos. of experiments is carried out which is determined by design of experiment (DOE). The Table 5 gives the experimental data. With the experimental data a nonlinear regression model is obtained using response surface methodology (RSM). The values of Tool wear and surface roughness for all experiments conducted with the combination of machining parameters are presented in Table 6. Analyses of variance (ANOVA) for the adequacy of the models are then performed in the subsequent steps. The F ratio calculated for 95 % level of confidence for each response. The values which are less than 0.05 are considered significant and the values greater than 0.05 are not significant and the models are adequate to represent the relationship between machining parameters and responses. Since turning is non-linear process in nature the linear polynomial will not be able to predict the response accuratelytherefore the second order model (quadratic model) is used. It is observed form the adequacy test by ANOVA that linear terms speed; feed and depth of cut are significant.

Table 6: Input and output of experiment

	Coded Data			Actual Data			Measured Response
S.No	**DOC (mm)**	**Feed Rate (mm/rev)**	**Speed Rate (RPM)**	**DOC (mm)**	**Feed (mm/rev)**	**Speed (RPM)**	**Tool Wear**
01	-1	1	-1	0.08	0.17	0900	0.0004160
02	0	0	0	0.18	0.12	1400	0.0002175
03	0	0	0	0.18	0.12	1400	0.0002173
04	1	1	1	0.12	0.17	1900	0.0005218
05	0	0	0	0.18	0.12	1400	0.0002180
06	0	0	-1	0.08	0.12	1400	0.0002735
07	1	-1	1	0.12	0.07	1900	0.0002049
08	0	0	0	0.18	0.12	1400	0.0002172
09	-1	1	1	0.12	0.17	0900	0.0002489
10	1	0	0	0.08	0.12	1900	0.0007529
11	-1	-1	1	0.12	0.07	0900	0.0002135
12	1	-1	-1	0.08	0.07	1900	0.0004617
13	0	-1	0	0.18	0.07	1400	0.0000820
14	0	1	0	0.18	0.17	1400	0.0001495
15	-1	0	0	0.18	0.12	0900	0.0005198
16	1	1	-1	0.08	0.17	1900	0.0008906
17	0	0	0	0.18	0.12	1400	0.0002172
18	-1	-1	-1	0.08	0.07	0900	0.0002669
19	0	0	1	0.12	0.12	1400	0.0000619
20	0	0	0	0.18	0.12	1400	0.0002181

Table 7: ANOVA Table for Tool wear estimated regression coefficients

Term	Coef	SE Coef	T	P
Constant	0.000229	0.000013	17.958	0.000
Speed (A)	0.000117	0.000012	9.928	0.000
Feed (B)	0.000100	0.000012	8.490	0.000
DOC (C)	-0.000106	0.000012	-9.000	0.00
Speed * Speed (A*A)	0.000389	0.000022	17.363	0.000
Feed * Feed (B*B)	-0.000131	0.000022	-5.868	0.000
DOC * DOC(C*C)	-0.000080	0.000022	-3.549	0.005
Speed * Feed (A*B)	0.000070	0.000013	5.340	0.000
Speed * DOC (A*C)	-0.000051	0.000013	-3.854	0.003
Feed * DOC (B*C)	-0.000028	0.000013	-2.147	0.057
S = 0.0000371633			PRESS = 9.676909E-08	

R^2 = 98.42%	R^2(pred) = 95.91%	R^2(adj) = 96.99%

The levels of significance for the linear terms depth of cut, feed rate, speed are depicted in Table 7. The fit summary recommends that the quadratic model is statistically significant for analysis of tool wear. For the appropriate fitting of tool wear the non-significant terms are eliminated by the backward elimination process. The ANOVA table for the quadratic model for tool wear. The results indicate that the model is significant (R2 and adjusted R2 are 98.42% and 96.99%). The final response equation for tool wear is

$$\text{Tool wear} = 0.000229 + 0.000117\,A + 0.000100\,B - 0.000106\,C + 0.000389\,A*A - 0.000131\,B*B - 0.000080\,C*C + 0.000070\,A*B - 0.000051\,A*C - 0.000028\,B*C$$

To analyse the data checking of goodness of fit of the model is very much required. The model adequacy checking includes the test for significance of the regression model, test for significance on model coefficients and test for lack of fit. For this purpose ANOVA is performed.

Table 8: Analysis of variance for tool wear

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.000001	0.000001	0.000000	69.11	0.000
Linear	3	0.000000	0.000000	0.000000	83.89	0.000
Square	3	0.000000	0.000000	0.000000	107.44	0.000
Interaction	3	0.000000	0.000000	0.000000	15.99	0.000
Residual Error	10	0.000000	0.000000	0.000000		
Lack-of-Fit	5	0.000000	0.000000	0.000000	16945.17	0.000
Pure Error	5	0.000000	0.000000	0.000000		
Total	19	0.000001				

Adequacy Checking for Variation of Tool Wears with Respect to Input Parameters by RSM:

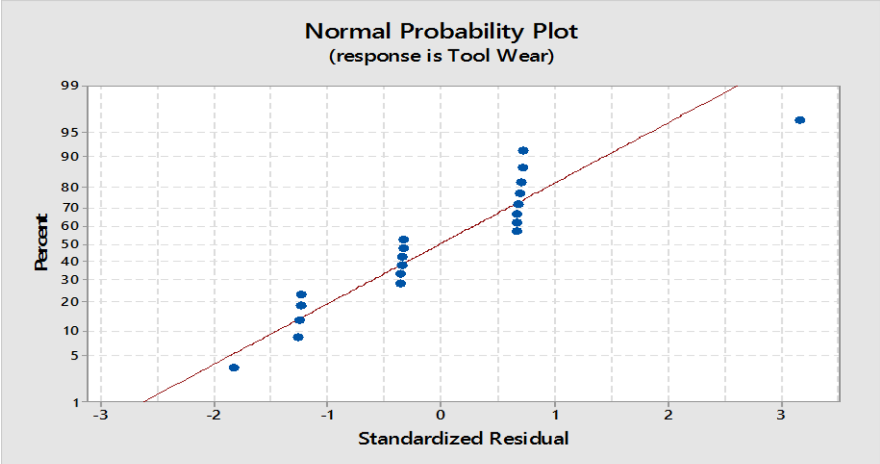

Figure 14: Normal probability plot of residual for tool wear

The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality. From Fig.14 it can be said that the data set is normally distributed.

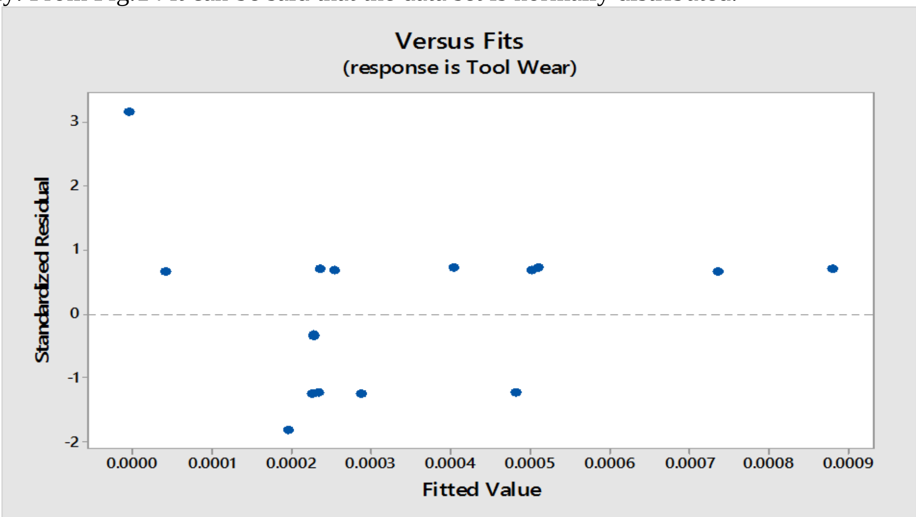

Figure 15: Plot of residuals vs. fit for tool wear

Residual vs. Fits plot is to provide a visualization of how well a statistical model fits the data. It provides a graphical alternative to the coefficient of determination. From Fig.15 Residuals are close to 0 for small x values and also for large x values. Therefore the regression model is quite normally distributed.

Analysis of Tool Wear by Minitab:

Figure 16 illustrates the tool wear with respect to input parameters RPM and feed rate. The value of tool wear is shown to decrease with decrease of RPM and feed rate.

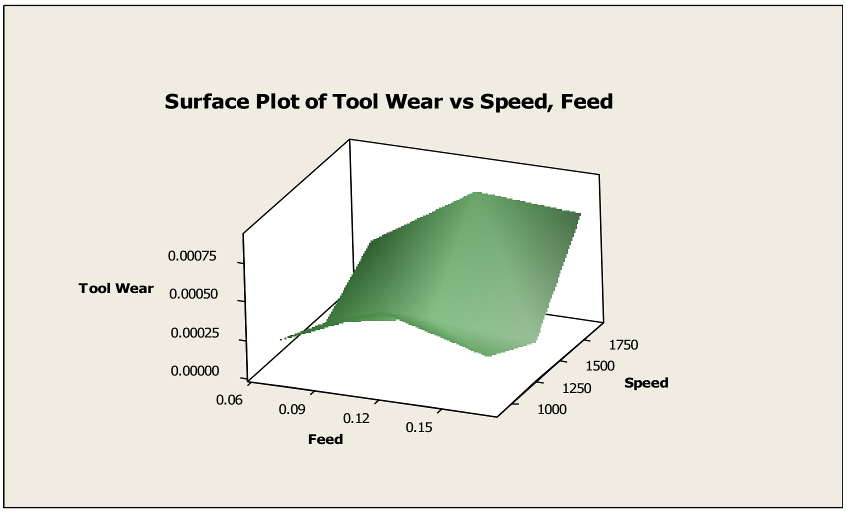

Figure 16: Variation in tool wears according to change in RPM and feed

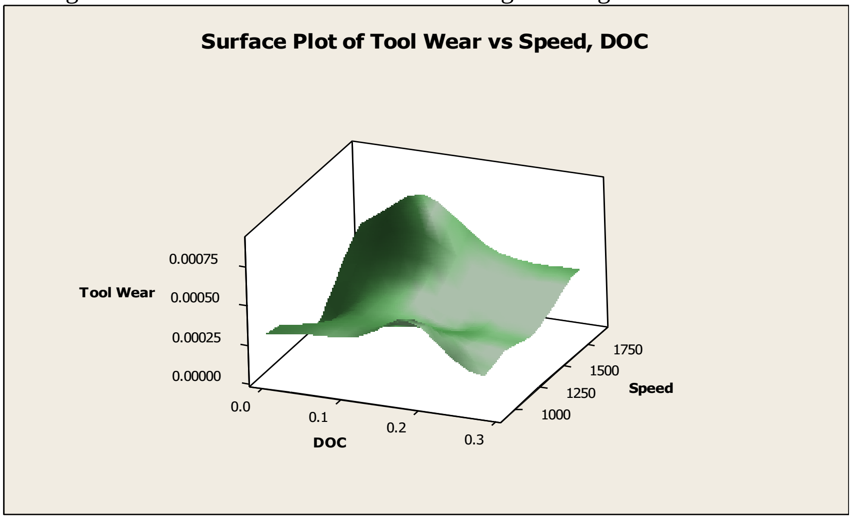

Figure 17: Variation in tool wears according to change in RPM and DOC

In Fig.17 the tool wear with speed and depth of cut is depicted. Tool wear decreases with decrease in speed and depth ofcut.

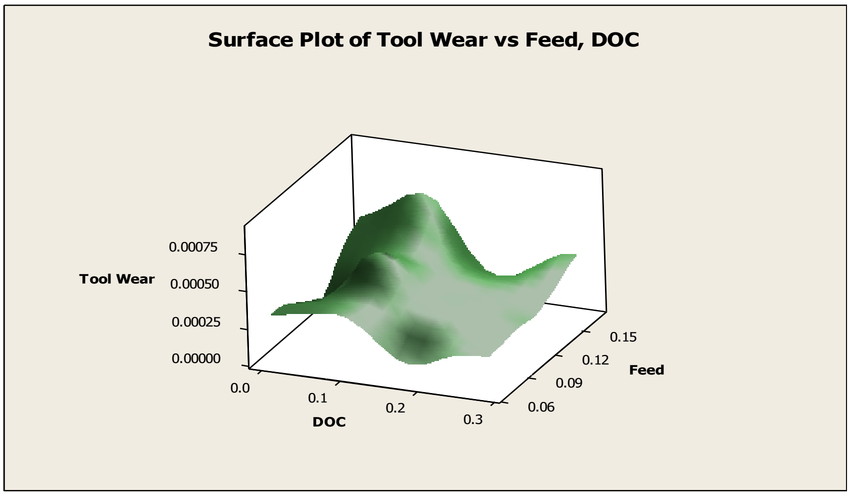

Figure 18: Variation in tool wear according to change in feed and DOC

In Figure 18 the tool wear with feed and depth of cut is depicted. Tool wear decreases with decrease in feed and depth of cut.

5. Conclusion:

Manufacturing processes like CNC high speed turning are heavily practised in almost all type of industry specifically in automotive industry, aeronautical industry etc. Thus it is very important to know the machining performance for a particular machining condition. In this investigation, responses were predicted for a set of machining parameters and also optimum machining conditions are evaluated considering each of the responses.

- ✓ During the present investigation, twenty no. of experiments are carried out. From the analysis of responses. it has been revealed that all the responses vary in the same nature with respect to the change in speed, feed rate and depth of cut.
- ✓ The measured results are satisfactory. Measurements are close to manual measurements which are done with a microscope for tool wear and stylus for surface roughness. However, the measurement system has problems when the wear on the tool has not yet formed properly. At current state, the measurement system, depending on cutting conditions, may require a few cuts, before the system can give reliable results.
- ✓ Experimental results show that the tool wear of the work materials are correlated with each other and influences of cutting parameters on tool wear and surface roughness are given. These figures show that both responses are affected as same manner.
- ✓ The result of optimization considering the responses showed the optimum conditions for the responses with the optimum value. According to the optimization, developed model seems to be satisfactory because the predicted results are in acceptable range with respect to the experimental result.

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