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EXPERIMENTAL INVESTIGATION OF THE PROCESS PARAMETERS DURING TURNING OPERATION ON CAST IRON

[1]M. Dhanenthiran, [1]A. Nagadeepan, [1]T. David Ubharasamy
[1]Asst Prof, Department of Mechanical Engineering, TRP Engineering College, Trichy.

Abstract-Every industry will expect the quality and time consumption for each and every product. In this work, we have investigated the effect of the process parameters in turning operation on cast iron using titanium carbide (insert). We have analyzed the results based on the factors like surface roughness, machining time, metal removal rate, tool wear. We conducted the various test in the cast iron by varying the speed, depth of cut, feed. Each and every reading are calculated and analyzed.

From this investigation, we have analyzed that quality will be improved by maximum spindle speed, maximum depth of cut and the feed. From the result, we found that the quality will be achieved high on cast iron using titanium carbide insert. Based on this project, we can conclude that machining of cast iron using titanium carbide insert combination gives better results than the other materials.

The above work was designed by using L18 orthogonal array and 18 experiments were carried out by this process. The mathematical model, ANOVA and graphs are drawn by using the DESIGN EXPERTS SOFTWARE.

Index Terms—Time consumption, Surface roughness, MRR ANOVA, DESIGN EXPERT SOFTWARE

I. INTRODUCTION

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. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool
- 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.

ADJUSTABLE CUTTING FACTORS IN TURNING

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

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. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

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 the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

Depth of Cut
Depth of cut is practically self explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

CUTTING TOOL MATERIAL

Titanium carbide

TiC, is an extremely hard (Mohs 9-9.5) refractory ceramic material, similar to tungsten carbide.

It is commercially used in tool bits. It has the appearance of black powder with NaCl-type face centered cubic crystal structure. It is mainly used in preparation of cermets, which are frequently used to machine steel materials at high cutting speed.

The resistance to wear, corrosion, and oxidation of a tungsten carbide-cobalt material can be increased by adding 6-30% of titanium carbide to tungsten carbide.

Tool bits without tungsten content can be made of titanium carbide in nickel-cobalt matrix cermets, enhancing the cutting speed, precision, and smoothness of the work piece. This material is sometimes called high-tech ceramics and is used as a heat shield for atmospheric re-entry of spacecraft. The substance may be also polished and used in scratch-proof watches.

It can be etched with reactive-ion etching.

The mineralogical form is very rare and called (Ti,V,Fe) C.

Properties of TIC

Molecular formula	TiC
Molar mass	59.89 g/mol
Appearance	black powder
Density	4.93 g/cm3
Melting point	3160 °C, 3433 K, 5720 °F

Boiling point	4820 °C, 5093 K, 8708 °F
Solubility in water	insoluble in water

Structure of TIC

Crystal structure	Cubic, cF8
Space group	Fm3m, No. 225
Coordination geometry	Octahedral

TURNING MACHINE

Lathes used in manufacturing can be classified as engine, conventional, turret, automatics, and numerical control etc. They are heavy duty machine tools and have power drive for all tool movements. They commonly range in size from 12 to 24 inches swing and from 24 to 48 inches center distance, but swings up to 50 inches and center distances up to 12 feet are not uncommon. Many engine lathes are equipped with chip pans and built-in coolant circulating system.

OUTPUT PARAMETERS

Material Removal Rate (MRR)

The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm3/min. For each revolution of the work piece, a ring shaped layer of material is removed.

$$MRR = (v.\,f\,.d \times 1000)\ in\ mm^3 / \min$$

Tool Wear

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and work piece. Specifically, tool wear is described by wear rate (volume loss per unit area per unit time) and is strongly determined by 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 temperatures arise because the chip slides at high speed along the tool rake face while exerting very high normal pressures (and friction force) on 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. Hence cutting tools need:

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

Measurement of Surface Roughness

Inspection and assessment of surface roughness of machined work pieces can be carried out by means of different measurement techniques.

1. Direct measurement methods

Direct measurement methods are used to find the surface roughness of the material in direct contact with the work piece. Every work piece is placed in the v-block for better rigidity and to hold every component easily to test the surface roughness.

II LITERATURE REVIEW

Tugrul ozel et al. [1] has experimentally investigated the effect of cutting edge geometry work piece hardness, feed rate and cutting speed on surface roughness and forces by hard turning of AISI H13 steel bar using CBN cutting tools and statistical analysis of variance was performed. The Factors considered in this investigation are cutting edge geometry, work piece hardness and cutting conditions. The responses are Surface roughness and effect of cutting forces in turning. The results predicted that the effect of cutting edge geometry on the surface roughness is remarkably significant. The cutting forces are influenced not only by cutting conditions but also the cutting edge geometry and work piece surface hardness.

M. Aruna et al. [2] has conducted experimental study on inconel 718 by finish hard turning using ceramic cutting tools. The machining conditions selected in this work are cutting speed, feed and depth of cut. The objective functions are Flank wear and surface roughness. The results predicted that less tool wear and good surface finish can be obtained at low cutting speeds.

E.D. Derakhshan and A.A. Akbari [3] has investigated experimentally the effect of work piece hardness and cutting speed on the surface quality and tool wear in hard turning. The parts AISI 4140 alloy steel were exposed to different thermal treatments. These hardened parts are machined with CBN cutting tools at different cutting conditions. The process parameters considered in this investigation are cutting speed and work piece. The results predicted that increasing of cutting speed had considerable effect on surface roughness.

M. Kaladhar et al. [4] has conducted experimental work on AISI 202 Austenitic stainless steel by hard turning using CVD coated cemented carbide tools. The process parameters such as Cutting speed, feed and nose radius. The results predicted that cutting speed and nose radius are influenced on surface roughness.

M. V. R. D. Prasad et al. [5] has conducted experiment on EN31 bearing steel using PCBN cutting tool the process parameters selected are cutting speed, feed and depth of cut. His predictions shows the surface roughness increased with increase of speed and depth of cut is not influencing much on roughness but the roughness value increasing non linearly with increasing feed.

Adeel H. Suhail et al. [6] has analyzed the effect of cutting parameters on Medium carbon steel AISI 1020 steel by hard turning using CNMG 432 TT 5100 inserts. The process parameters considered in his work are cutting speed, feed and depth of cut. The objective functions are work piece surface temperature and surface roughness. The results predicted that lower the work piece temperature will lead to better surface finish.

S. Ranganathan et al. [7] has conducted experimental investigation on AISI 316 steel by hard turning using WC inserts. The cutting parameters chosen here are speed, feed and depth of cut. The responses are surface roughness and Tool wear. In this work mathematical model was developed for surface roughness and Tool wear and the proposed models can be used to values of surface roughness of AISI 316 steel and tool of WC insert within the range.

S.Thamizhamanii et al. [8] as conducted experimental investigation on martensitic stainless steel (SS 440C) by hard turning with CBN cutting tools. He process parameter selected in this work is cutting speed, feed and depth of cut. The objective function is tool flank wear minimization. The results predicted that flank wear occurred at low cutting speed with high feed rate and more depth of cut. The flank wear also due to heat generated at low cutting speed. The influence of tool flank wear was due to abrasive action between tool tip and cutting tool, hard carbides in the work piece material.

S.S Mahapatra et al. [9] has analyzed by hard turning operation. The process parameter consider in this analysis are cutting speed, feed and depth of cut. The responses as surface roughness. The results predicted that the surface roughness increased with an increase of cutting speed.

Farhad Kolahan and Mahadi Abachizadeh [10] has analyzed turning parameter of cylindrical parts. The machining parameter are selected in this work are cutting speed , feed and depth of cut. The output is to minimize the total cost of machining process. In this simulated annealing method was used to optimize the parameter. The results predicted that the total cost is minimized at particular cutting speed, feed and depth of cut. They predicted that the machining cost has the greatest share in the overall cost.

S.Thamizhamanii et al. [11] has conducted experimental investigation on AISI 8620 by hard turning using coated carbide ceramic tool. The Cutting condition speed, feed and depth of cut. The Output as tool wear and Surface Roughness. The results predicted that surface roughness decreased when cutting speed was increased.

S.Thamizhamanii et al [12] has conducted experimental investigation on SCM 440 alloy steel by hard turning using coated ceramic tool. The process parameters are cutting speed; feed and depth of cut are chosen in this work. The responses as surface roughness. The results predicted that the depth of cut has significant role to play in producing lower surface roughness followed by feed. Taguchi gave systematic simple approach and efficient method for the optimum operating condition.

T. Thamizhaarasan et al [13] has analyzed on materials having hardness values over 45 HRC in „C‟ scale hardness tester by hard turning with three grades of PCBN cutting tool. The process parameter cutting speed, feed and depth of cut are selected at different ranges. The responses flank wear, tool life and MRR. The results are predicted that A grade CBN content tool generated a better surface finish with a lower flank wear rate and the depth of cut has negligible effect on surface finish and flank wear of cutting tool and the feed too has little effect.

S. Thamizhamanii and S.Hasan [14] has conducted experimental work on AISI 440 C martenstic stainless steel and SCM 440 alloy by hard turning which is hardness between 50 to 70 HRC with CBN and PCBN cutting tool. The process parameter selected in this work feed rate, cutting speed and depth of cut. The objective function is to minimize the flank wear and crater wear. The results predicted that flank wear formation was mainly by abrasion and crater formation was by rough surface saw tooth chips and also temperature of the rake face by stainless steel.

Ty G. Dawson et al. [15] has analyzed wear trend in hard turning with PCBN cutting tool. The cutting conditions selected in this work speed, feed and depth of cut. The objective function is to find out wear the pattern of PCBN cutting tools. The results predicted that flank wear patterns that could currently help tool life under certain cutting conditions

SCOPE OF THE PROJECT

To analyze the effect of process parameters the cutting speed, feed and depth of cut in machining process, turning of cast iron and formulate a mathematical model for responses metal removal rate, machining time and surface roughness to find optimal values of cutting parameters.

SELECTION OF OBJECTIVE FUNCTION

The above literature review has shown that less effort has been contribute for metal removal rate, machining time and surface roughness in turning operation on cast iron. Thus machining time, metal removal rate and surface roughness has been chosen as objective function of this work with cast iron steel as work piece material and TiC insert as cutting tool.

III EXPERIMENTAL SETUP

WORK PIECE MATERIAL

Cast iron is formed by remelting pig iron, and is useful for a variety of engineering purposes. Read on to know more on the unique properties of cast iron.

Cast iron is an alloy of iron and carbon, and is popular because of its low cost and ability to make complex structures. The carbon content in cast iron is 3% to 4.5% by weight. Silicon and small amounts of Manganese, Sulphur, and Phosphorus are also present in it. The products of cast iron exhibit reasonable resistance against corrosion. The cast iron is neither malleable nor ductile, and it cannot be hardened like steel. It melts at about 2100 ºF, and has either a crystalline or a granular fracture. The mechanical properties of cast iron are very much dependent on the morphology of its carbon content. Carbon is present in the form of plates in gray cast iron, whereas, it is incorporated in compound Fe_3C (cementite) in white cast iron. Nodular cast iron, which show better tensile strength and strain than gray cast iron, carry carbon in the form of sphere shaped graphite particles. Following are some of the properties of cast iron.

EXPERIMENTAL ARRANGEMENT

Machine tool	conventional lathe
Works specimen material	cast iron
Size	Φ30 mm X170 mm

Cutting inserts	CNMG
Tool material	Titanium carbide inserts
Tool holder size	12.5 X 12.5
Environment	Coolant not used
Surface roughness measurement	surface roughness tester
Metal removal rate calculation	Using by formula
Machining time measurement	Using by stop watch
Tool wear measurement	tool maker microscope
Cutting force measurement	lathe tool dynamometer

PROCESS PARAMETERS LEVEL

Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
68	1	0.1
45	1.25	0.2
30	1.5	-

EXPERIMENTAL PROCEDURE

The experiment was conducted using one work piece material namely cast iron with titanium carbide tool inserts. The tests were carried out for a length of 100 mm, 30mm diameter in a conventional lathe. Three levels of cutting speed, three levels of feed rate and two levels of depth of cut were used and are shown in table.

The table gives the various cutting parameter for each experiment the results are measured and displayed. The different units used here are cutting speed in m/min, feed in mm/rev, and depth of cut in mm. surface roughness in microns, metal removal rate in mm3/min and machining time in minutes, cutting force in kgf, Tool wear in Microns.

- The surface roughness was measured by surface roughness tester
- The metal removal rate was measured by using formulae
- The tool wear was measured by tool maker microscope.
- The cutting force was measured by lathe tool dynamometer.
- Machining time was measured by stop watch.

The analysis was made using popular software specifically used for design of experiment application known as design expert. The plan is made of 18 tests in which the first column was assigned to the cutting speed, the second column to the feed rate and third column to depth of cut. The outputs to be studied are surface roughness, metal removal rate and machining time.

DESIGN EXPERT AN OVER VEIW

New design

It consists of combined, mixture, response surface design and design method tool. In this we can select new design or already saved design. This is the first window to enter the design expert.

Response surface design

It is used to find the optimum process settings to achieve peak performance of our process. It consists of central composite design, box behnken, optimal, user defined and historical data method.

Responses

In this column we can enter the responses with respective units.

Actual design

After selection of our required responses the actual design window will be displayed. In this we must enter the selected input conditions and measured output values.

Analysis tool

After you have entered your response data in the design layout view choose a response by clicking on the corresponding node under analysis. It consists of transformation, fit summery, model, diagnostics, and model graphs.

L18 ORTHOGONAL ARRAY WITH OUTPUT VALUES

RUNS	CUTTING SPEED (m / min)	FEED (mm / rev)	DEPTH OF CUT (mm)	MACHINING TIME (min)	CUTTING FORCE (kgf)		MRR (mm3 / min)	SURFACE ROUGHNESS (Microns)	TOOL WEAR (Microns)
					X	Y			
1.	68	1	0.1	01:01	02	08	6833	3.934	0.00137
2.	68	1	0.2	01:03	11	23	13666	4 .193	0.00145
3.	45	1	0.1	01:34	03	10	4477	5.247	0.00153
4.	45	1	0.2	01:36	12	21	8956	4.711	0.00170
5.	30	1	0.1	02:30	02	10	2969	3.727	0.00163
6.	30	1	0.2	02:25	12	20	5938	4.235	0.00173
7.	68	1.25	0.1	00:58	02	09	8541	3.362	0.00128
8.	68	1.25	0.2	00:55	12	35	17082	3.508	0.00142
9.	45	1.25	0.1	01:20	03	14	5596	5.151	0.00146
10.	45	1.25	0.2	01:22	10	23	11192	2.119	0.00168
11.	30	1.25	0.1	02:04	02	08	3711	4.384	0.00158
12.	30	1.25	0.2	02:06	14	30	7422	5.876	0.00178
13.	68	1.5	0.1	00:45	04	30	10249	4.329	0.00176
14.	68	1.5	0.2	00:53	06	28	20498	1.753	0.00198
15.	45	1.5	0.1	01:10	02	10	6715	3.550	0.00164
16.	45	1.5	0.2	01:11	19	51	13430	4.275	0.00169
17.	30	1.5	0.1	01:45	04	16	4453	4.750	0.00163
18.	30	1.5	0.2	01:48	09	19	8906	5.270	0.00174

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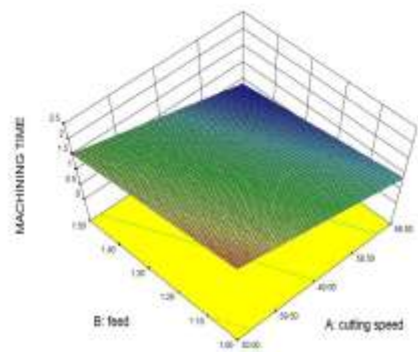
OUTPUT MODEL GRAPH

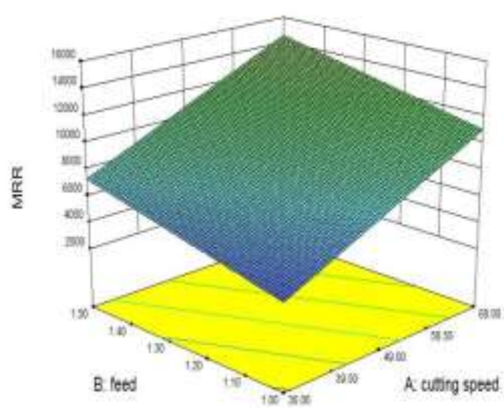
The response surface method graphs are used to analyse three parameters at a time. This Interaction graph can be used to display any factor interactions that are present. The Cube is a great way to display the relationship between three significant factors.

Graph - Machining Time



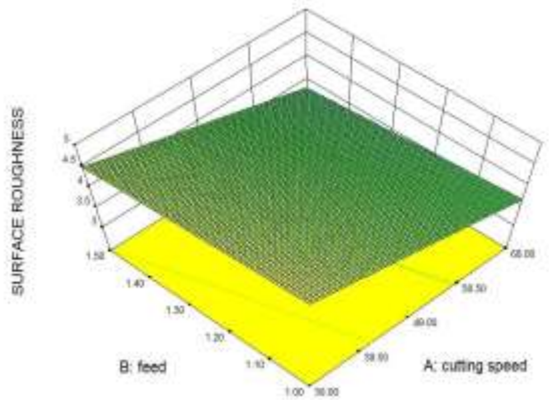
If cutting speed and feed increases the machining time is less at high depth of cut.

Graph - Metal Removal Rate



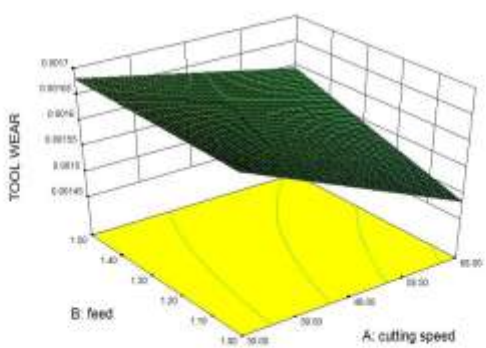
If cutting speed and feed increases the MRR also increases at high depth of cut

Graph - surface roughness



If cutting speed and feed increases the surface roughness will be low at high depth of cut.

Graph - tool wear



If cutting speed and feed increases the tool wear is low at high depth of cut

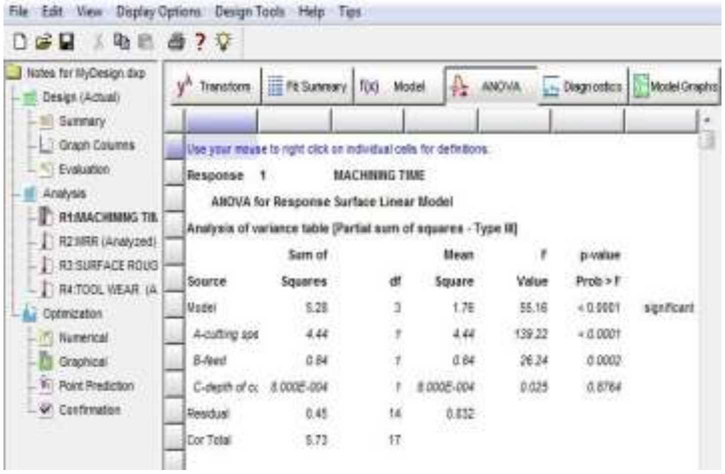
ANOVA TEST RESULTS

ANOVA TABLE - MACHINING TIME

The present contribution of various process parameters on the selected characteristics can be estimated by performing ANOVA. Thus the information about how significant the effect of each controlled process parameter is obtained.

From the table it is clear that the selected model is significant as predicted "F" value is less than P. It is shown the process parameters cutting speed, feed and depth of cut have significant effect on machining time.

The obtained results are analyzed using design expert software and all the values are shown in table. The results obtained by this method was formed as equation by the same software and given as equation.



Response 1 MACHINING TIME

ANOVA for Response Surface Linear Model

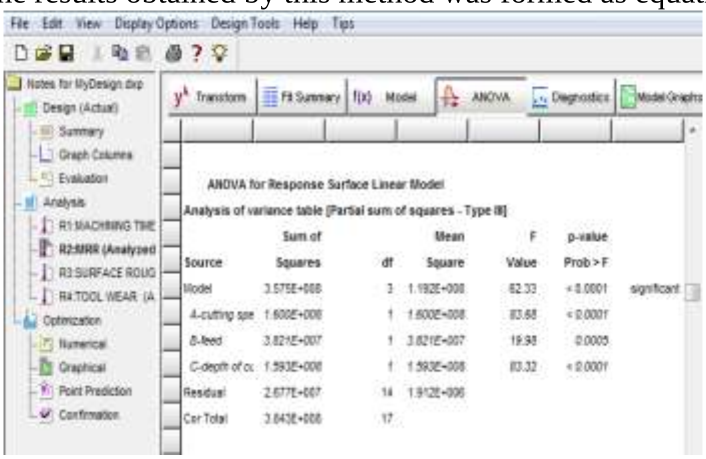
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.28	3	1.76	55.16	< 0.0001	significant
A-cutting spe	4.44	1	4.44	139.22	< 0.0001	
B-feed	0.84	1	0.84	26.24	0.0002	
C-depth of cu	8.000E-004	1	8.000E-004	0.025	0.8764	
Residual	0.45	14	0.032			
Cor Total	5.73	17				

ANOVA TABLE - METAL REMOVAL RATE

From the table it is clear that the selected model is significant as predicted "F" value is less than P. It is shown the process parameters cutting speed, feed and depth of cut has significant effect on metal removal rate.

The obtained results are analyzed using design expert software and all the values are shown in table. The results obtained by this method was formed as equation by the same software and given as equation.



ANOVA for Response Surface Linear Model

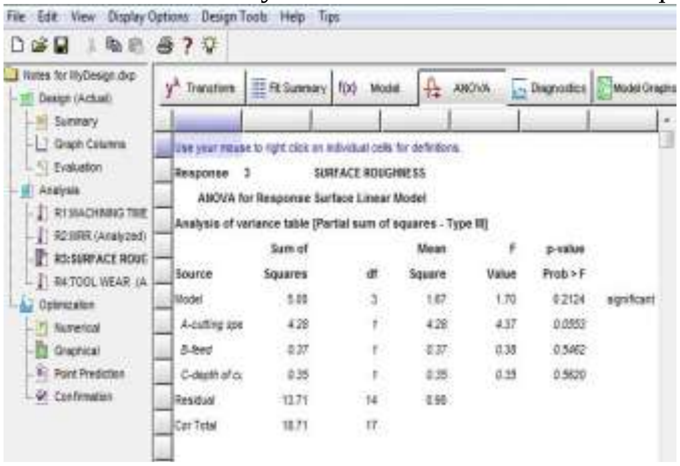
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.575E+008	3	1.192E+008	62.33	< 0.0001	significant
A-cutting spe	1.600E+008	1	1.600E+008	83.68	< 0.0001	
B-feed	3.821E+007	1	3.821E+007	19.98	0.0005	
C-depth of cu	1.593E+008	1	1.593E+008	83.32	< 0.0001	
Residual	2.677E+007	14	1.912E+006			
Cor Total	3.843E+008	17				

ANOVA TABLE - SURFACE ROUGHNESS

From the table it is clear that the selected model is significant as predicted "F" value is less than P. It is shown the process parameters cutting speed, feed and depth of cut has significant effect on surface roughness.

The obtained results are analyzed using design expert software and all the values are shown in table. The results obtained by this method was formed as equation by the same software and given as equation.



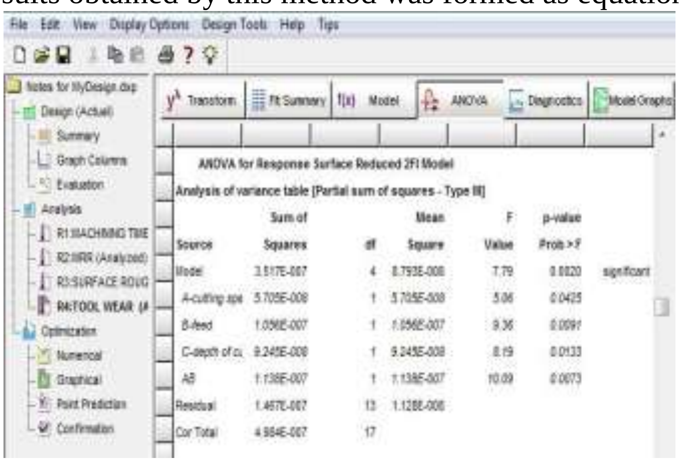
Response 3 SURFACE ROUGHNESS
ANOVA for Response Surface Linear Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.00	3	1.67	1.70	0.2124	significant
A-cutting spe	4.28	1	4.28	4.37	0.0553	
B-feed	0.37	1	0.37	0.38	0.5462	
C-depth of cu	0.35	1	0.35	0.35	0.5620	
Residual	13.71	14	0.98			
Cor Total	18.71	17				

ANOVA TABLE-TOOL WEAR

From the table it is clear that the selected model is significant as predicted "F" value is less than P. It is shown the process parameters cutting speed, feed and depth of cut has significant effect on tool wear.

The obtained results are analyzed using design expert software and all the values are shown in table. The results obtained by this method was formed as equation by the same software and given as equation.



ANOVA for Response Surface Reduced 2FI Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3.517E-007	4	8.793E-008	7.79	0.0020	significant
A-cutting spe	5.705E-008	1	5.705E-008	5.06	0.0425	
B-feed	1.056E-007	1	1.056E-007	9.36	0.0091	
C-depth of cu	9.245E-008	1	9.245E-008	8.19	0.0133	
AB	1.138E-007	1	1.138E-007	10.09	0.0073	
Residual	1.467E-007	13	1.128E-008			
Cor Total	4.984E-007	17				

MATHEMATICAL MODEL

A mathematical model is to generated for the above proposed responses. In this a linear multi variate regression model is generated for surface roughness.

The correlation between the factors cutting speed, feed and depth of cut and measured surface roughness/metal removal rate/ machining time/ tool wear were obtained by multiple linear regression analysis. The mathematical model suggested was in the following form

$$Y = n\beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3 + \ldots + \beta nxn + €$$

Here y is the performance output terms and β are model constant. The constants were calculated using linear regression analysis with the help of design expert software and the following relations were obtained. The calculated co efficient from design expert software were substituted in equation

MATHEMATICAL MODEL - SURFACE ROUGHNESS

SURFACE ROUGHNESS = -3.54790 + 0.14740 * V + 5.55596 * F + 27.82938 * D - 0.098615 * V * F - 0.36889 * V * D - 10.41333 * F * D

MATHEMATICAL MODEL-METAL REMOVAL RATE

MRR = +9092.07113 - 190.78238 * V - 7273.92721 * F - 60594.23415 * D + 152.62784 * V * F +1271.81377 * V * D + 47573.33333 *F * D

MATHEMATICAL MODEL - MACHINING TIME

MACHINING TIME =+4.98262 -0.046955 * V -1.73143 * F -1.22975 * D +0.011429 * V * F +5.86897 E-003 * V * D +0.86667* F * D

MATHEMATICAL MODEL - TOOL WEAR

TOOL WEAR = +2.68143E-003 -3.51232E-005 * V -8.74864E-004 * F +1.06840E-003 * D +2.49272E-005 * V * F +2.41128E-006 * V * D +2.00000E-004 * F * D

RESULT AND CONCLUSIONS

The following results were obtained from turning of hardened cast iron at various cutting conditions. This work presents the findings of an experimental investigation of the effect of feed rate, depth of cut and cutting speed on the surface roughness ,tool wear, metal removal rate and machining time in turning operation of cast iron by design expert response surface design.

- It is concluded that the performance of titanium carbide inserts is better at high cutting speed and high feed of turning operation.
- It is found from the results less surface roughness and high metal removal rate are obtained using titanium carbide inserts on cast iron at high cutting speed and high feed.
- If cutting speed and feed increases the machining time will be less at high depth of cut.
- If cutting speed and feed increases the MRR also increases at high depth of cut.

- If cutting speed and feed increases the surface roughness will be low at high depth of cut.
- If cutting speed and feed increases the tool wear will be high at high depth of cut
- The design expert response surface design gives systematic simple approach and efficient method for optimum operating conditions. This investigation gives how to use response surface design and to obtain optimum condition with lowest cost minimum number of experiments and industrial engineers can use this method.
- Using experimental data a multiple linear regression model is developed and proves to be effective in optimizing the cutting condition in turning operation.

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