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Prediction of Surface Roughness in Turning of Al 6061 Alloy by TAGUCHI

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ABSTRACT : *Surface roughness has received serious attention for many years. It has been an important design feature and quality measure in many situations. In this work, experiments were conducted to analyze surface roughness on 6061 aluminum alloy using various machining variables such as a cutting speed, feed rate, depth of cut and nose radius. This data was used to develop surface roughness prediction models, as a function of cutting speed, feed, and tool nose radius, for each individual material. Purpose of this study is to develop a technique to predict a surface roughness of part to be machined according to cutting parameters. This work focuses on developing a regression technique for surface roughness prediction in turning. The trained regression technique was used in predicting surface roughness for cutting conditions and tested using test data. The experiment results show, regression technique can be successfully used for predicting surface roughness.*

Keywords: *Coolant, Machining, Surface Roughness, Surface texture, TAGUCHI,*

I. INTRODUCTION

1.1 Machining:

Machining is a shading process whereby material is removed from a part to give it specific dimensions and a particular surface finish, within a range of given tolerance values. This operation is part of an overall manufacturing process that includes a series of shaping operations. Machining allows a part to be given its final geometry once it has been shaped by rolling, forging or casting. Machining by chip removal is carried out through the mechanical action of a cutting tool. This machining operation is carried out on a machine tool.

1.2 Types of Machining:

The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping; planning, boring, broaching and sawing. Lathes are the principal machine tool used in turning. Milling machines are the principal machine tool used in milling. Drilling operations are done primarily in drill presses but sometimes on lathes or mills.

1.3 Surface Roughness:

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

a) Surface texture: It is the pattern of the surface which deviates from a nominal surface. The deviations may be repetitive or random and may result from roughness, waviness, lay, and flaws.
b) Roughness: It consists of surface irregularities which result from the various machining process. These irregularities combine to form surface texture.
c) Roughness height: It is the height of the irregularities with respect to a reference line. It is measured in

millimeters or microns or micro inches. It is also known as the height of unevenness.
d) Roughness width: It is the distance parallel to the nominal surface between successive peaks or ridges which constitute the predominate pattern of the roughness. It is measured in millimeters. Roughness width cut off is the greatest spacing of respective surface irregularities to be included in the measurement of the average roughness height. It should always be greater than the roughness width in order to obtain the total roughness height rating. It is rated in thousandths of an inch. Standard tables list roughness width cutoff values of 0.003, 0.10, 0.030, 0.100, 0.300 and 1.000 inches. If no value is specified, a rating of 0.030 is assumed. Lay represents the direction of predominant surface pattern produced and it reflects the machining operation used to produce it.

Fig: 1.1 Fish Bone diagram with factors that influence on surface roughness

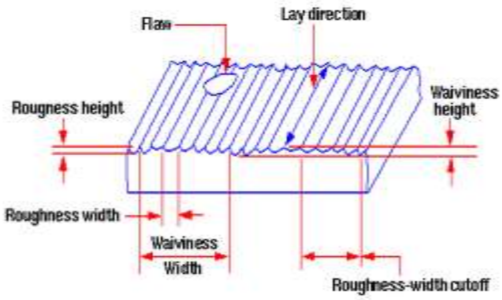


Fig: 1.2 Surface Characteristics

e) Waviness: Waviness refers to the irregularities which are outside the roughness width cut off values. Waviness is the widely spaced component of the surface texture. This may be the result of work piece or tool deflection during machining, vibrations or tool run out. Waviness should include all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length.
f) Waviness width: It is the spacing of successive wave peaks or wave valleys, which is rated in inches.
g) Waviness height: It is the peak to valley distance of the surface profile, measured in millimeters. Flaws are unintentional, unexpected, and unwanted interruptions in the topography typical of a part surface.
h) Roughness sampling length: It is the sampling length within which the roughness average is determined. This length is chosen, or specified, to separate the profile irregularities which are designated as roughness from those irregularities designated as waviness.

i) Roughness average (Ra):
This parameter is also known as the arithmetic mean roughness value, AA (arithmetic average) or CLA (center line average). Ra is universally recognized and the most used international parameter of roughness.

$$R_a = \frac{1}{L}\int_0^L |\,Y(x)\,|\,dx$$

Where Ra = the arithmetic average deviation from the mean line, L = the sampling length, y = the ordinate of the profile curve It is the arithmetic mean of the departure of the roughness profile from the mean line.
j) Root-mean-square (rms) roughness (R*q*):
This is the root-mean-square parameter corresponding to R*a:*

$$R_q = \sqrt{\left\{\frac{1}{L}\int_0^L [Y(x)]^2\,dx\right\}}$$

Where: Ra = the arithmetic average deviation from the mean line, L= the sampling length, y= the ordinate of the profile curve It is the arithmetic mean of the departure of the roughness profile from the mean line.

1.4Turning
Turning is one of the main types of machining where material is removed using a cutting tool. It allows rotating parts to be produced using a single-edge cutting tool.

1.4.1 Cutting parameters
a) 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).

b) 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, 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.

c) 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 figure 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 (in mm) of the work piece before the cut is started. It is expressed in surface mm per minute, 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.

Cutting parameters: (a) Depth of cut d_p (mm), (b) Feed per rotation f (mm/rev), (c) Cutting speed v_c (m/min)

$$N = \frac{1000 \times v_c}{\pi \times d}$$

The cutting parameters are at the root of the following performance parameters:

The feed rate VF (mm/min), $\boldsymbol{VF = f \times N}$

The material removal rate Q (cm^3/min), $\boldsymbol{Q = DP \times f \times VC}$

Cutting power is an important parameter, especially in the case of rough operations,

The required cutting power P_c (kW) can be estimated using the following formula:

$$P_c = \frac{F_c \times v_c}{6000}$$

v_s. cuttingspeed (m/min)

F_{ace} cutting force (N) $\boldsymbol{F_{ace} = k_c \times d_p \times f}$,

Therefore with the units used

d_p depth of cut (mm)

f feed rate (mm/rev)

k_c specific cutting energy coefficient (N/mm^2)

In the case of aluminum alloys, the specific coefficient is low compared to steels (3 times lower) but the cutting speeds used are high (5 to 10 times higher than for steel). This leads to high power outputs combined with high rotational speeds, which are not always attainable in turning because the centrifugal forces induced by unbalances in parts can lead to vibrations and, at worst, can cause parts to become unscrewed and to be thrown off the chuck.

Specific cutting force k_c (N/mm^2):

The specific cutting force is primarily a function of:

1. Material being machined
2. Feed
3. Cutting geometry
4. Tool wears

1.4.2 Process Variables

Surface roughness in turning depends mainly on cutting speed, Depth of cut, Feed and Nose radius.

1.5 Tool Material

The field of application of grades of cutting material, other than high-speed steel, has been standardized with two symbols. Among the most common are: HF fine-grain carbide (for good cutting edge sharpness), HC-coated carbide to improve wear resistance ,Highly wear resistant DP polycrystalline diamond for high speeds or abrasive alloys, commonly known as PCD

1.5.1 Selection of operating conditions 1

The choice of operating conditions: cutting speed, feed per rotation, depth of cut. Is made primarily according to: (a) Type of alloy being machined, (b) The grade and geometry of the tool (angels and dimensions, corner radius) (c) The severity of the operation (section of chips from rough turning, impact machining, finishing) With constraints and limitations relating to: Quality (precision, surface condition), the machine's characteristics (power, torque, rotational speeds and feed rates) safety (rotational speed limited by the clamping chuck, by part unbalances), Techno-economic manufacturing criteria (productivity, cost), which depend on tool life and therefore on the cutting parameters selected.

1.5.2 Selection of operating conditions 2

Selection of depth of cut:

In the case of rough turning this is limited by the turning allowance (or) by the machine characteristics.

Selection of feed:

For rough turning, this is linked to insert geometry and pass depth. This feed must be restricted to present chips from jamming in soft and sticky alloys. It is also limited by the machines characteristics. For finishing, it is selected according to surface condition, with the help of a geometric formula.

1.5.3 Selection of operating conditions 3

Range of basic cutting speeds v_c in m min^{-1}

Alloy characteristics	Family of alloys	HF carbide v_c (m min^{-1})	Diamond-coated HC carbide v_c (m min^{-1})	Polycrystalline diamond v_c (m min^{-1})
Without silicon	1,000-3,000-5,000	300-2,000	Up to 2,500	Up to 2,500
Without silicon	2,000-7,000	300-2,000	Up to 2,500	Up to 2,500
High hardness 100 HB	21,000			
With silicon	6,000	250-1,500	Up to 2,000	Up to 2,500
Low content Si<13%	41,000			
Average content	42,000	250-750	Up to 1,000	Up to 2,000
Si>13%				
Hypereutectic		125-400	Up to 500	Up to 1,000
Si>17%				
Composite				Up to 500

Table: 1.1 Range of cutting speeds with different alloy characteristics

II. PROBLEM DEFINITION

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product. Surface quality is one of the most specified customer requirements. Major indication of surface quality on machined parts is surface roughness. Turning using carbide tools allows manufacturers to simplify their processes and still achieve the desired surface roughness. There are various machining parameters that affect the surface roughness, but those effects have not been adequately quantified. In order maximize gains of manufacturers from utilizing finish turning, accurate predictive models for surface roughness to be constructed.

Accordingly, to the past modeling methods on surface roughness prediction can be classified into two categories i.e., Geometric modeling and regression analysis. As a type of analytical modeling method, geometric modeling is based on the motion geometry of a metal cutting process regardless the cutting dynamics. As described previously, analytical models tend to be general and computationally straightforward. The major drawback with the geometric modeling method is that they missed other parameters is cutting dynamics including speed, depth of cut and the work piece material in their models. The second major drawback with this modeling method is that they did not verify their model with any experimental data.

This work utilizes the taguchi method to optimize the number of experiments to be done on the work piece for variety of cutting conditions in turning operation. The mathematical equation is obtained from regression analysis and surface roughness is calculated.

This work considers four variety of cutting parameters that are speed, feed, depth of cut and nose radius. A set of experimental data performed on aluminum 6061 were taken and there surface roughness was measured using surface roughness measuring tester. It also shows effect of each cutting parameter over surface roughness.

III. EXPERIMENTAL SETUP

This experiment involves a basic factorial design, which includes four controlled factors. The response variable for this design is surface roughness, measured in micro meters (µm.). The controlled factors include the four main parameters con-trolled in a turning operation.

1. Cutting speed, 2. Feed rate, 3. Depth of cut, 4. Nose radius

The experimental setup for this methodology is intended to generate samples and collect all data based on the individual experimental runs. This setup includes all hardware and software needed to generate turned surfaces, measure their surface roughness, collect all necessary data, and analyze this data. The hardware used in this experimental setup includes a CNC Lathe, sample work pieces, and a surface roughness measurement setup. Coolant used is in the lathe IPOL AQUA CUT 125.

Fig: 3.1 CNC Turning Machine

Fig: 3.2 Roughness measuring tester

3.1 Surface Roughness Measuring Tester

The instrument used for measuring surface finish was surface roughness measuring tester. This device consists of a tracer head and an amplifier. The head housed a diamond stylus, having a point radius of 0.003mm, which been against the surface of the work and may be moved by hand or it may be another driven. Any movement of the stylus covered by surface irregularities is converted into electric fluctuations by the tracer head. These signals are magnified by the amplifier and registered on the digital display. The readings shown on the digital display indicates the average height of the surface roughness. The roughness tester cut-off value is 0.8mm. An average of three measurements was used as a response value.

3.2 Material Used

Component	Wt. %	Component	Wt. %
Al	95.8 - 98.6	Si	0.4 - 0.8
Cr	0.04 – 0.35	Ti	Max 0.15
Cu	0.15 - 0.4	Zn	Max 0.25
Fe	Max 0.7	Other, each	Max 0.05
Mg	0.8 - 1.2	Other, total	Max 0.15
Mn	Max 0.15		

Table: 3.1Chemical Composition of 6061 Aluminum Alloy

Hardness, Brinell	95
Hardness, Rockwell A	40
Hardness, Rockwell B	60
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Modulus of Elasticity	68.9 GPa
Machinability	50 %
Shear Modulus	26 GPa
Shear Strength	207 MPa
Poisson's Ratio	0.33
Fatigue Strength	96.5 MPa

Table 3.2 Mechanical properties of6061 Aluminum Alloy

The experimental values we got from machining are used as training data and testing data. After that the prediction and optimization has been done. The training data and testing data without coolant and with coolant as shown in Tables 6.3 and 6.4.

Levels	Speed(rpm)	Feed rate(mm/rev)	Depth of cut(mm)	Nose radius(mm)
1	1000	0.05	0.5	0.4
2	1500	0.15	0.75	0.8
3	2000	0.25	1	1.2

Table: 3.3 Cutting Parameters

3.3 Cutting Tool Used

Tungsten carbide is an inorganic chemical compound containing equal parts of tungsten and carbon atoms. Tungsten carbide is often simply called carbide. In its most basic form, it is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, tools and abrasives. Tungsten carbide is high melting point as 2,870 ^{0}C and extremely hard.

3.4 Coolant Used

A coolant is a fluid which flows through a device to prevent its overheating, transferring the heat produced by the device. An ideal coolant has high thermal capacity, low viscosity, is low-cost, non-toxic, and chemically inert, neither causing nor promoting corrosion of the cooling system. IPOL AQUA CUT 125 especially suited for tough materials and operations. High performance mineral oil-based micro-emulsions are used to extent tool life and super surface finish.

S.No	S(rpm)	D(mm)	F(mm/rev)	R(mm)	Experimental R_A (µm)	Predicted R_A(µm)	% Accuracy
1	1200	0.65	0.07	0.4	0.35	0.31	89
2	1200	0.75	0.1	0.8	0.5	0.44	88
3	1200	0.85	0.2	1.2	0.96	0.98	98
4	1600	0.65	0.1	1.2	0.36	0.40	90
5	1600	0.75	0.2	0.4	1..30	1.22	94
6	1600	0.85	0.07	0.8	0.39	0.32	82
7	1800	0.65	0.2	0.8	1.53	1.47	96
8	1800	0.75	0.07	1.2	0.40	0.35	88
9	1800	0.85	0.1	0.4	0.84	0.74	88
						Avg.Accuracy	90%

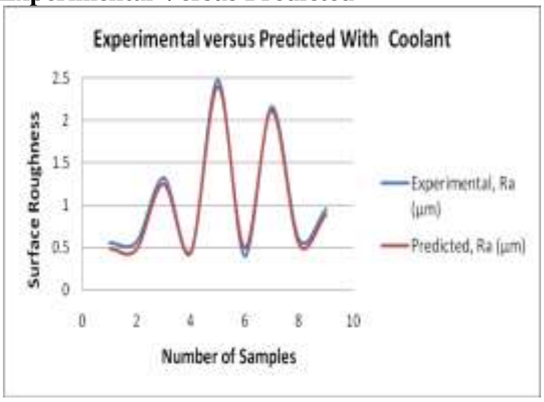
Table: 3.8 Validation Data without Coolant

S.No	S(rpm)	D(mm)	F(mm/rev)	R(mm)	Experimental R_A (µm)	Predicted R_A(µm)	% Accuracy
1	1200	0.65	0.07	0.4	0.56	0.49	88
2	1200	0.75	0.1	0.8	0.57	0.48	84
3	1200	0.85	0.2	1.2	1.32	1.25	95
4	1600	0.65	0.1	1.2	0.45	0.44	98
5	1600	0.75	0.2	0.4	2.47	2.40	97
6	1600	0.85	0.07	0.8	0.4	0.50	80
7	1800	0.65	0.2	0.8	2.16	2.11	98
8	1800	0.75	0.07	1.2	0.6	0.54	90
9	1800	0.85	0.1	0.4	0.96	0.89	93
						Avg.Accuracy	92%

Table: 3.9 Validation Data with Coolant

IV .RESULTS AND DISCUSSION

4.1 Experimental Versus Predicted



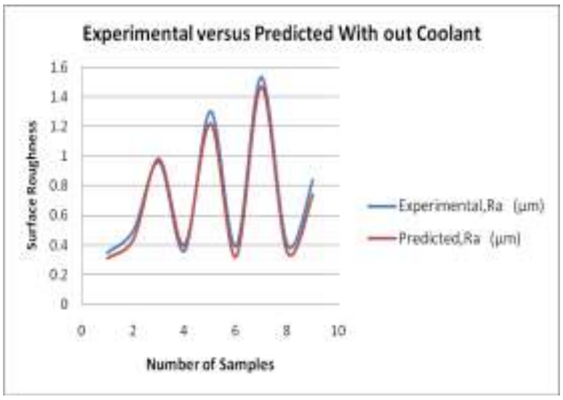


Fig 4.1 Experimental Versus Predicted With Out Coolant

Fig 4.2 Experimental Versus Predicted With Coolant

In the above graphs predicted regression values and experimental values are taken on y-axis and sample numbers are taken on x-axis. If we observe the above graphs we can conclude that the predicted values are close to experimental values and we use the regression technique.

4.2 Roughness at Constant Speeds

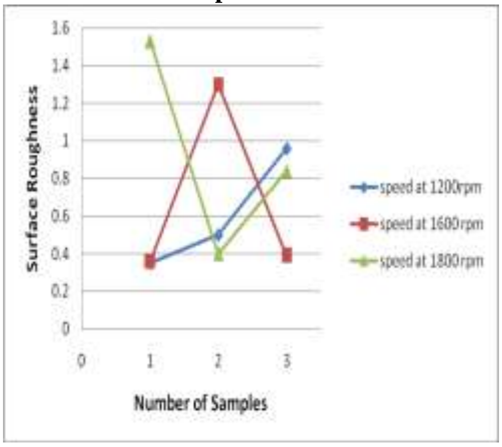


Fig 4.3Variation of Surface Roughness at Constant Speed without Coolant

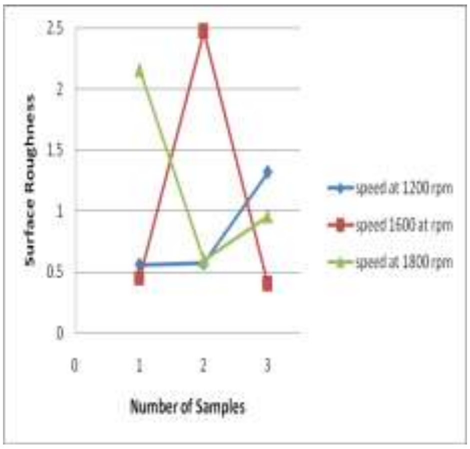


Fig 4.4 Variation of Surface Roughness at Constant Speed with Coolant

Graph shows the variation of surface roughness for various speeds and it can be observed that the speed is a dominant factor influencing the surface roughness in machining.

Hard and strong materials require a lower cutting speed. Where as soft and ductile materials are cut at higher cutting speeds .For example cemented carbides, ceramics and H.S.S will cut at much higher cutting speeds than alloy or carbon steel tools.

4.3 Roughness at constant feeds

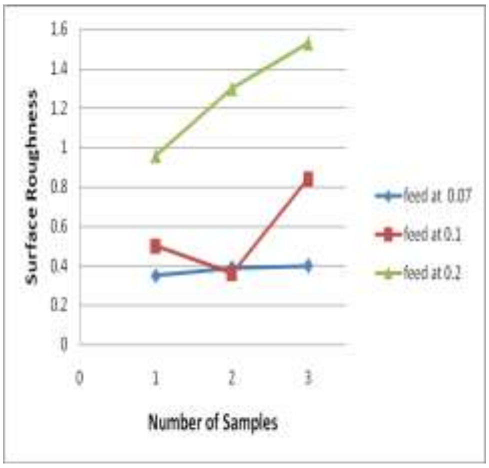


Fig 4.5 Variation of Surface Roughness at Constant Feed Without Coolant

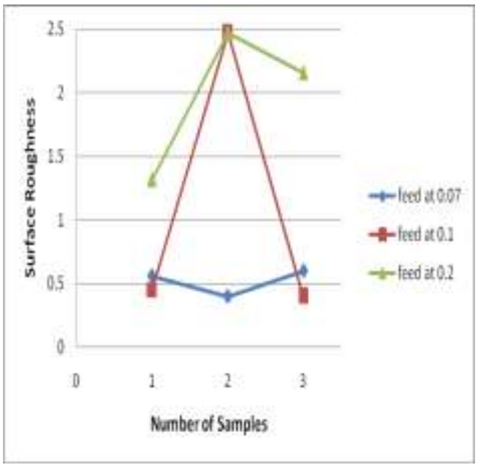


Fig 4.6 Variation Of Surface Roughness At Constant Feed With Coolant

Graph shows the variation of surface roughness for various feed rates. From graph it can be observed that minimum value of surface roughness is achieved , when feed rate is 0.07mm and the roughness value increases with increasing feed rates .It is obvious that the feed appears as a dominant influential factor on surface roughness .Optimum surface roughness can be achieved by setting the feed as low as possible.

4.4 Roughness at Constant Depth of Cuts

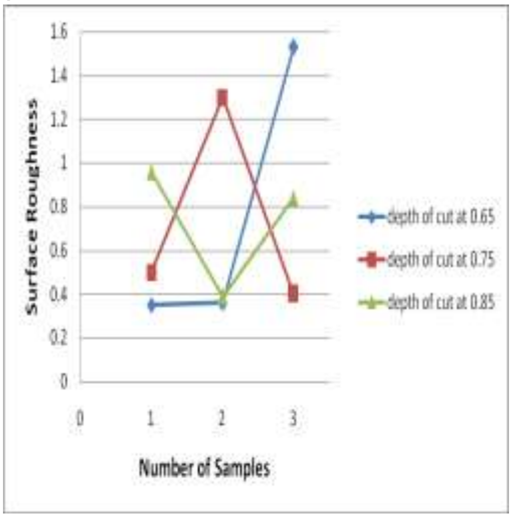


Fig 4.7 Variation of Surface Roughness at Constant Depth of Cut without Coolant

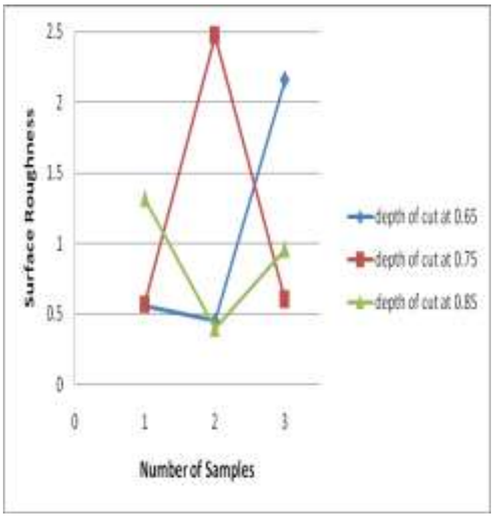


Fig 4.8 Variation of Surface Roughness at Constant Depth of Cut with Coolant

Graph shows the variation of surface roughness for depth of cuts and can be observed that there is a little variation in the surface roughness. The results of the performed research show that both feed and cutting speed influence on surface roughness but the feed is the most influential factor. The depth of cut has a negligible influence on the surface roughness. The minimum surface roughness can be achieved by setting the feed as low as possible and the cutting speed as high as possible

4.5 Roughness at Constant Nose Radius

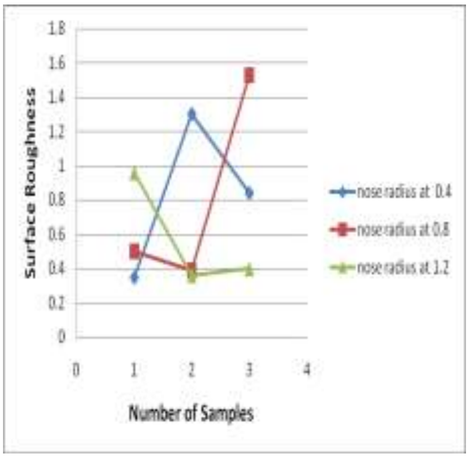


Fig 4.9 Variation of Surface Roughness at Constant Nose Radius without Coolant

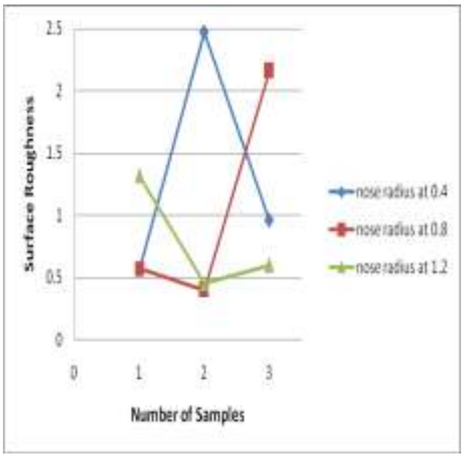


Fig 4.10 Variation of Surface Roughness at Constant Nose Radius with Coolant

Graph shows the variation of surface roughness for different nose radii and can be observed that there is a little variation in the surface roughness. The nose radius has a negligible influence on the surface roughness.

V. CONCLUSIONS

The regression approach has been applied accurately to turning operation for predicting surface roughness. The proposed methodology has been validated by means of experimental data on dry and wet turning and is found to be quite effective. In this technique, the equations are developed by using training data, further these are applied to predict the surface roughness. The surface roughness is predicted for testing data and compared with the experimental surface roughness. Regression model gives better predictions, with an accuracy of 90% without using coolant and 92% with using coolant. The experimental and predicted values of surface roughness showed that,the regression can be successfully applied for predicting surface roughness .The graphs of performed work show that both feed and cutting speed influence on surface roughness but the feed is the most influential factor. The depth of cut has a lesser influence on the surface roughness. The graph show that as speed increases surface roughness decreases and surface roughness increases with feed increases. The minimum surface roughness can be achieved by setting the feed as low as possible and the cutting speed as high as possible.

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