2

REVIEW OF LITERATURE

2.1 Introduction

The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Surface roughness is used as the critical quality indicator for the machined surfaces and has influence on several properties such as wear resistance, fatigue strength, coefficient of friction, lubrication, wear rate and corrosion resistance of the machined parts. In today's manufacturing industry, special attention is given to dimensional accuracy and surface finish. Turning is the primary operation in most of the production processes in the industry. The turning operation produces the components, which have critical features that require specific surface finish. The operators working on lathe use their own experience and machining guidelines in order to achieve the best possible surface finish. Due to inadequate knowledge of the complexity and factors affecting the surface finish in turning operation, an improper decision may cause high production costs and low machining quality. The proper selection of cutting tools and process parameters for achieving high cutting performance in a turning operation is a critical task. Hence a proper estimation of surface roughness has been the focus of study for several years. Therefore, it is important for the researchers to model and quantify the relationship between roughness and the parameters affecting its value. The determination of this relationship remains an open field of research, mainly because of the advances in machining and materials technology and the available modeling techniques.

Various researchers have used different methods such as Factorial designs, Response surface methodology and Taguchi methods, which are now widely use in place of one factor at a time experimental approach which is time consuming and exorbitant in cost [12]. A brief about their work and also its details work is given in next session.

2.2 Review of Literature

Martin [1] uses a reduced scale model for the analysis of machine tool structure for milling machine. Author has selected "Perspex" material for preparation of prototype model. Perspex appears to be satisfactory model material at least for structure which all are made from one basic material. Bahl et al. [4, 6] used different ribbing pattern for machine structure design. The diamond shaped ribs are far the best type of ribbing configuration investigated. The diagonal and cross ribs are not very effective in suppressing the panel and pseudo bending modes. Gupta and Somsundaram [5] used stiffened machine tool column by FEA method. For similar stiffening arrangement internal vertical stiffeners are better under bending loads while under torsional loads external vertical stiffener are more efficient. Columns having internal horizontal stiffeners are stiffer than those having external horizontal stiffeners. Morgan and Rahman et al. [7, 9 and 11] given review of most common machine tool structure materials and their properties are compared, including modulus of elasticity, specific stiffness, damping, long term dimensional stability, coolant resistance, wear rate ,frictional properties, thermal conductivity and lead time for manufacture. Also described "Epoxy concrete" a new material for machine tool structure design. Radhakrishna and Reddy [8] have work on centre lathe, slant bed and Plano Millar for the optimization as the requirement of accuracy and stability of machine tools and suggests the best option regarding thermal distortions and guide ways deformations. Balkrishna [16] prepare a dynamic cutting force model for the process of three dimensional turning operations. The dynamic force model developed was incorporated into a computer program to obtain time saving chatter predictions. Experimental tests were performed on AISI 4140 steel work pieces to justify the chatter predictions of the dynamic cutting process model in both the finishing and roughing regimes. Tarng and Lee [17] used piezoelectric inertia actuator which is mounted on the cutting tool and acted as a tuned vibration absorber for the suppression of chatter in turning operations. It is shown that the tuned vibration absorber can modify the frequency response function of the cutting tool so as to improve cutting stability in turning operations.

Banson [27] prescribes a chatter prediction model for face turning operation including tool wear effect and measure the effect of different parameters such as depth of cut, roughness value etc. This model can be use with complex geometry tools to accurately predict the magnitude and direction of the process damping force. The process damping model was added to a dynamic shearing and static wear force model to create a complex three dimensional dynamic machining force model. Ramezanali [32] prepare a dynamic model of turning machine and compare the frequency by FEM modal and modal testing. Details of the other literature reviews are given below.

W. S. Lin, B.Y. Lee, C.L. Wu [18] 2001

In this paper, an abductive network is adopted to construct a prediction model for surface roughness and cutting force. To verify the precision of the abductive network, regression analysis has been adopted in the paper to develop a second prediction model for surface roughness and cutting force. Investigational results are provided to confirm the effectiveness of this approach.

J.Paulo Davim [19] 2001

In this paper authors have used Taguchi (L_{27}) method to establish a correlation between cutting velocity, feed and depth of cut with the roughness evaluating parameters Ra and Rt . The cutting tests were made on a 6 KW lathe with free machining steel. It was observed that cutting velocity has superior influence on the roughness followed by the feed. The depth of cut has no significant influence on the roughness.

O. B. ABOUELATTA, J. Madl [20] 2001

Authors have used FFT analyzer to measure tool vibrations in radial and feed directions. The surface roughness was measured using Surtronic 3+ measuring instruments. The measured results were collected and analysed with the aid of the commercial software package MATLAB, BC++ and SPSS. The predicted model that depends on both cutting parameters and tool vibrations are more accurate than those depending on cutting parameters only. The maximum height roughness parameter Rt depends greatly on the rotational cutting speed and work piece diameter

B.Y. Lee, Y.S. Tarng [21] 2001

Lee and Tarng have used computer vision to inspect surface roughness of a workpiece under a variation of turning operations. A polynomial network using a self-organizing adaptive modeling method is applied to constructing the relationships between the feature of the surface image and the actual surface roughness under a variation of turning operations. It was concluded that surface roughness of the turned part can be predicted with reasonable accuracy with the image of the turned surface and turning conditions

M.Y.Noordin, V. C. Venkatesh, C. L. Chan, A. Abdullah [22] 2001

Noordin, Venkatesh and Abdullah have work with turning of AISI 1010 steel. The cutting performance tests concerned 18 trials. The response variables measured were the cutting forces and the surface roughness. The cutting forces were measured using 3-component dynamometer (Kistler, Type 9265 B), a multi channel charge amplifier (Kistler, Type 5019A) and a data acquisition system. The surface roughness of the turned surface was measured using roughness tester (Mitutoyo, Surftest 301). The tangential force was much higher than the other forces at any particular experimental trial. The surface roughness measurements obtained increases when the cutting speed was increased.

A.E. Diniz, R. Micaroni [24] 2002

The experiments were carried out on a rigid CNC lathe with a 22 kW main motor with AISI 1045 steel. The tools were TNMG 160404-PF and TNMG 160408-PF (ISO P15 carbide inserts coated with TiC, Al2O3 and TiN). Surface roughness was monitored using a portable roughness meter. One experiment consisted of turning the work piece with a cutting edge up to the point it reached flank wear of VB=3 mm. Fig. 2.1 shows surface roughness for all the conditions. It was concluded that use of cutting fluid provides longer tool life than dry cutting, but a higher feed reduces the difference in tool life between wet and dry cutting. The increase of tool nose radius increases tool life and cutting power. To remove cutting fluid from the process it is necessary to decrease cutting speed, increase feed and nose radius

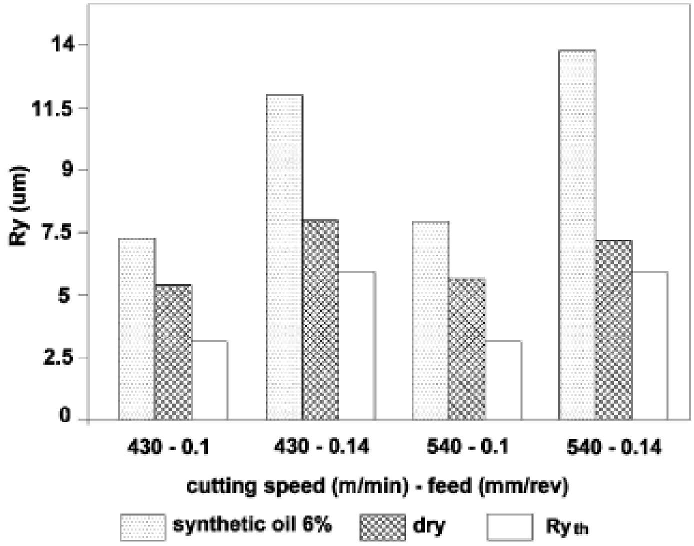

Fig. 2.1 Surface roughness (R_y) for all the conditions tested (r_ε =0.4mm) [24]

C. X. (Jack) Feng, X. Wang [25] 2002

Feng and Wang have used steel 8620 and AL 6061 T for the Development of Empirical Models for Surface Roughness Prediction in Finish Turning by regression analysis. They have selected 2^5-1 fractional design is selected. The design is shown in Table 2.1.These experiments are conducted on a production type YAM CK-1 CNC Lathe with a FANUC OT10 controller. Mitutoyo Surface Tester SJ-03 is used for the surface roughness measurement. To establish the prediction model, regression analysis is conducted with MINITAB using the above experimental data. Fig. 2.2 shows comparison of the fitted values and the estimated values with Equation and Fig. 2.3 shows the fitted values vs. the observed values. The approximation is statistically adequate based on hypothesis testing. It has been shown that the prediction results are better than those by using $R_i = \frac{f^2}{32\,r}$

Table 2.1 Factors and levels in the experiment [25]

Level	Hardness (A)	Feed (B)	Point angle (C)	Depth of cut (D)	Spindle speed (E)
Low(-1)	Steel 8620 (86 HRB)	0.051mm/rev	35^0	0.51 mm	95.71 m/min
High (+1)	AL 6061 T (52 HRB)	0.203 mm/rev	80^0	1.02 mm	143 m/min

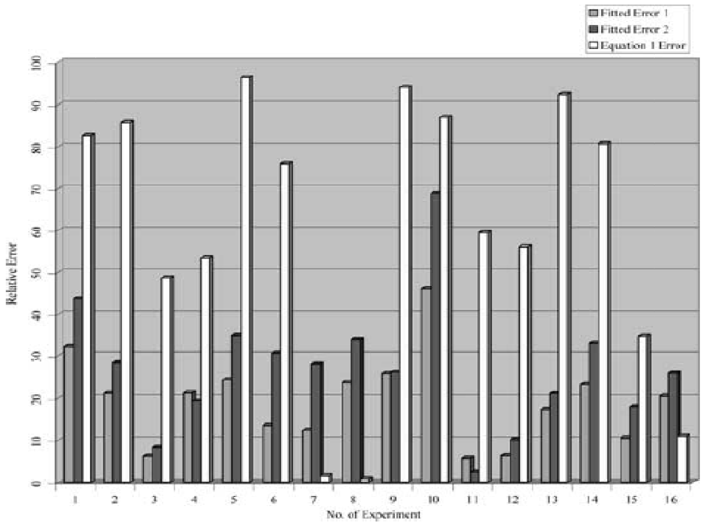

Fig. 2.2 Comparison of the fitted values and the estimated values with Eq. [25]

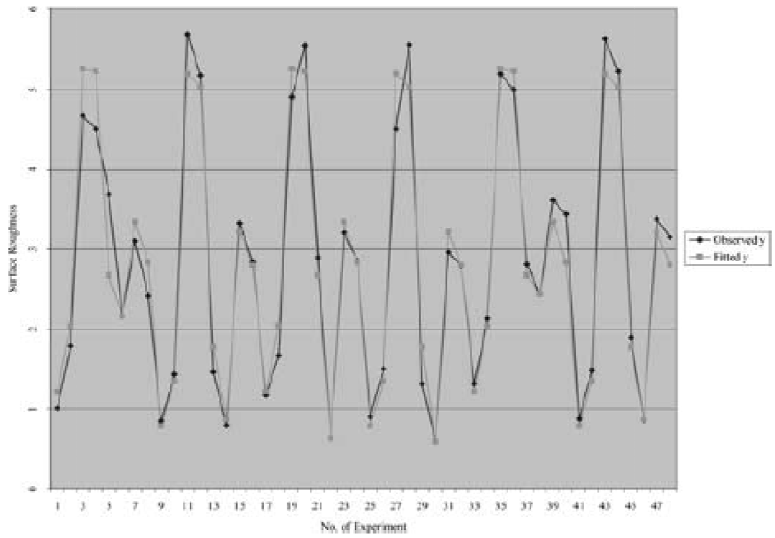

Fig. 2.3 The fitted values vs. the observed values [25]

P.V.S. Suresh, P. Venkateswara Rao, S.G. Deshmukh [26] 2002

In this work, investigational results were used for modelling using response surface roughness methodology (RSM). The experimental data was utilized to build mathematical model by regression method. Three level (3^4) factorial design of experiments was adopted for experimentation. A high precision NH–22 HMT lathe was used for experimentation on Mild steel. The cutting tools used for experimentation were

CNMG 120404, CNMG 120408, CNMG 120412 and of 4025 grade. A genetic algorithmic approach was used to obtain the machining conditions for the required surface finish. It was end that application of the GA approach to obtain optimal machining conditions will be quite useful at the Computer aided process planning stages in the production of high quality goods with tight tolerances by a variety of machining operations, and in adaptive control of automated machine tools.

I. Puertas Arbizu, C.J. Luis Perez [28] 2003

Puertas and Perez have used 2^3 factorial design with first order and second order model. Table 2.2 shows different levels of the variable used in the experiment. Once parts were manufactured, effective roughness was measured with an ALPA TL-70 roughness tester. It is seen that feed and depth of cut variables have a negative influence on the surface roughness average as increasing any of the two previous variables means increasing the roughness parameter.

Table 2.2 Levels of the variable used in the experiment [28]

	Lowest	Low	Centre	High	Highest
Coding	-1.47119	-1	0	1	1.47119
Cutting speed (m/min)	33	40	55	70	77
Feed (mm/rev)	0.01	0.05	0.13	0.2	0.24
Depth of cut (mm)	0.27	0.6	1.3	2	2.33

Chang Xue Fang, Xian Feng Wang [29] 2003

In this paper 2^5 full factorial design is used to facilitate model construction by RA and CNN. These experiments are conducted on a production type YAM CK-1 CNC Lathe with a FANUC OT10 controller. The surface roughness data of the shaft are collected with a surface profilometer (Mitutoyo Surface Tester SJ-03). To establish the prediction model, a software package MINITAB is used to carry out the regression analysis. Figure 2.4 shows predicted value Vs observed value and Figure 2.5 shows comparison of different method. The method used in this paper to test the goodness of fit of each model and to test whether the two models are equally good in modelling and predicting the surface roughness given the conditions used provides a valuable tool for many similar applications of modelling methods in engineering design and manufacturing.

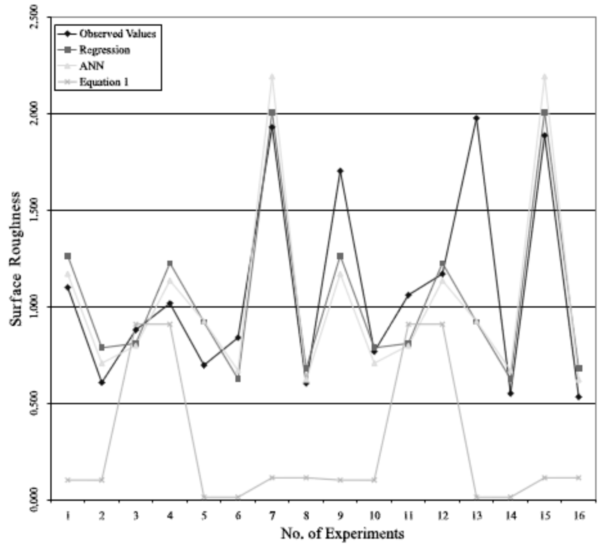

Fig. 2.4 Predicted values versus observed values. [29]

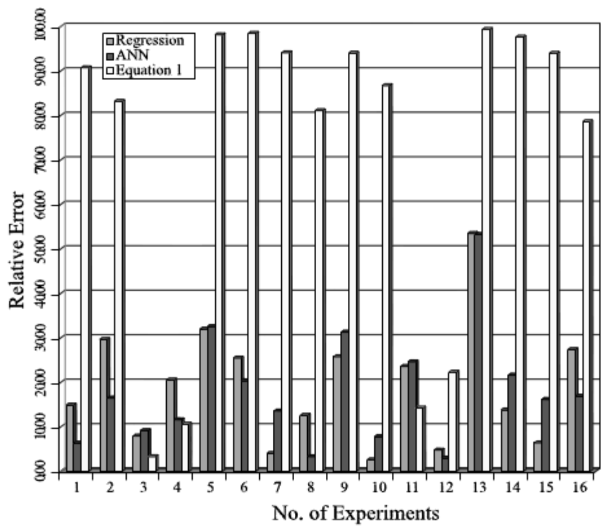

Fig. 2.5 Deviation of RA, CNN and Equation values from the observed values. [29]

M.Y. Noordin, V.C. Venkatesh, S. Sharif, S. Elting, A. Abdullah [30] 2004

Noordin, Venkatesh and Abdullah have used Response Surface Methodology for turning AISI 1045 steel. The factors investigated were cutting speed, feed and the side cutting edge angle (SCEA) of the cutting edge. The main cutting force, i.e. the tangential force and surface roughness were the response variables investigated. The experimental plan was based central composite design (CCD) and results were input into the Design expert software for analysis. Figs. 2.6 and 2.7 shows normal probability and Plot of residuals vs. predicted response. The ANOVA revealed that feed is the most significant factor influencing the response variables investigated. The SCEA^2 and the feed and SCEA interaction factors provided secondary role to the responses investigated. Furthermore, the cutting speed also provided secondary role to the tangential force.

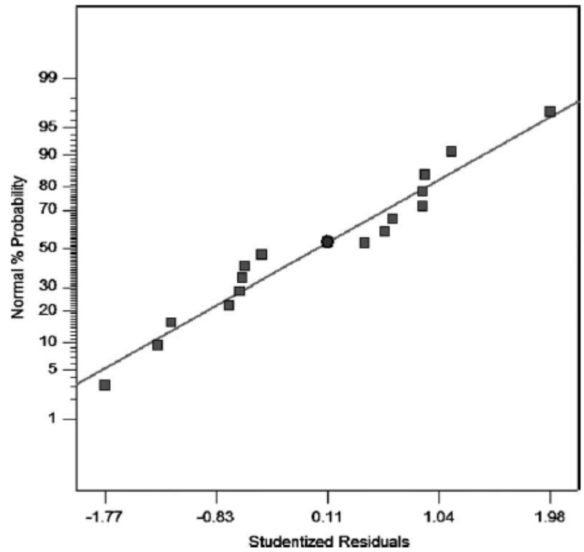

Fig. 2.6 Normal probability plot of residuals for *R*a data. [30]

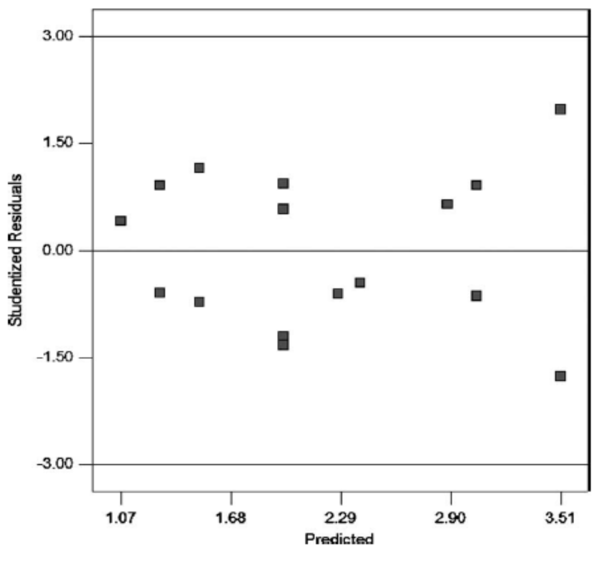

Fig. 2.7 Plot of residuals vs. predicted response for Ra data. [30]

Y. Kelvin Chou, Hui Song [31] 2004

Aim of the experiments was designed to investigate tool nose radius effects in finish hard turning. Ceramic inserts with tool nose radii ranged from 0.8 to 2.4mm were tested on AISI 52100 (HRC 61) steel bars with different machining conditions were conducted on a precision lathe. A triaxial force transducer was used to measure cutting forces during machining. Results prove that large tool nose radii only give finer surface finish, but comparable tool wear compared to small nose radius tools.

H. Oktema, T. Erzurumlu, H. Kurtaran [33] 2005

In this study, cutting experiments were planned using three-level full factorial (3^5) design. Cutting experiments are conducted considering five cutting parameters: feed, cutting speed, axial depth of cut radial depth of cut and machining tolerance. Milling operations are performed at the determined cutting conditions on a DECKEL MAHO DMU 60 P five axis CNC milling machine (Fig. 2.8). Surface roughness (Ra) values are measured from the mold surfaces with surf test 301 profilometer. Finally it was concluded that GA improved the surface roughness by about 10%. The predicted optimum cutting condition was validated with an experimental measurement. It was found that GA prediction correlates very well with the experiment.

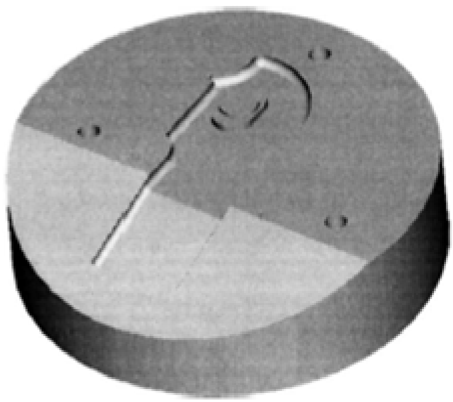

Fig. 2.8 Mold part [33]

T. Ozel, Y. Karpat [34] 2005

In this experiment, effects of cutting edge geometry (Fig. 2.9), work piece hardness, feed rate and cutting speed on surface roughness and tool wear in the finish dry hard turning of

AISI H13 steel were experimentally investigated. A 2^4 fractional factorial design was used. The factors and factor levels are summarized in Table 2.3. The developed prediction system is found to be competent of accurate surface roughness and tool wear prediction for the range it has been trained. The neural network models provided better prediction capabilities because they generally offer the ability to model more complex nonlinearities and interactions than linear and exponential regression models can offer.

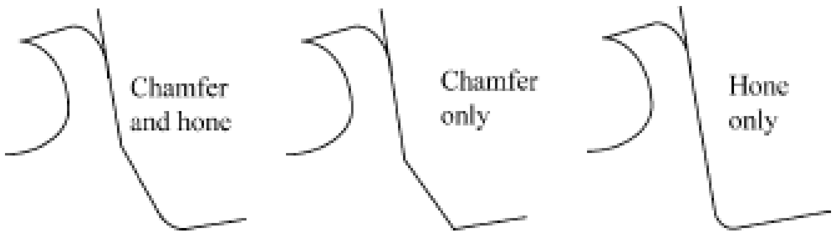

Fig. 2.9 Cutting with various edge geometry CBN tools [34]

Table 2.3 Experimental factors and levels [34]

Level	HRC	Edge geometry	V(m/min)	f(mm/rev)
Low	51.3	Honed	100	0.1
High	54.7	Chamfered	200	0.2

Yusuf Sahin, A. Riza Motorcu AR [35] 2005

Yusuf and Motorcu have used central composite design (18 Experiments) for the prediction of a surface roughness model for turning of Mild steel with coated carbide tools. Fig. 2.10 shows the resulting of 18 experiments forming a central composite design. The machine used for the turning tests was a John ford TC 35 Industrial type CNC lathe machine. TNMG 160408-MF2 was supplied by Seco for the machining test. The surface roughness of the carbon steel was measured by the aid of a stylus instrument. The established equations clearly show that the feed rate was main influencing factor on the surface roughness. It increased with increasing the feed rate but decreased with increasing the cutting speed and the depth of cut, respectively. It is seen that the first-order effect of feed rate and cutting speed is significant while depth of cut is insignificant.

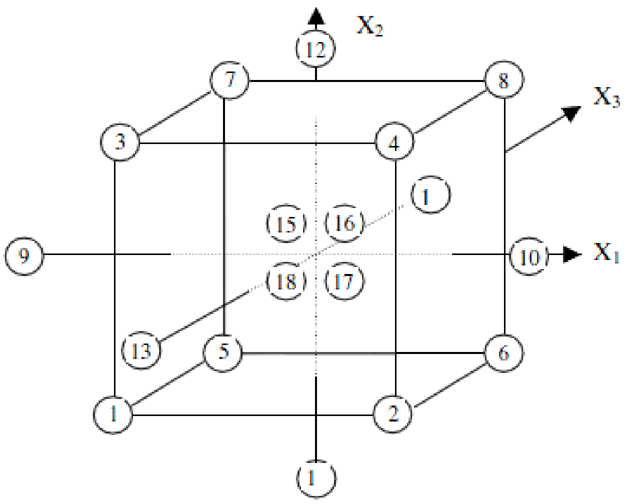

Fig. 2.10 Central composite design for three factors [35]

Mohamed A. Dabnum, M.S.J.Hashmi, M.A.EL-Baradie [36] 2005

Using RSM and 2^3 factorial design of experiment, mathematical model of surface roughness as a function of speed, feeds and depth of cut have been developed with 95% confidence level. The turning operations were performed on Mascot M1600 with Macor material. Surface roughness was measured using surface roughness tester (Mitutoyo 402). Finally it was concluded that the feed rate is the main influencing factor on the roughness, followed by the cutting speed and depth of cut. Dual-response contours (Fig. 2.11) provide useful information about the maximum attainable surface roughness for a given metal removal rate as a function of all three independent cutting variables.

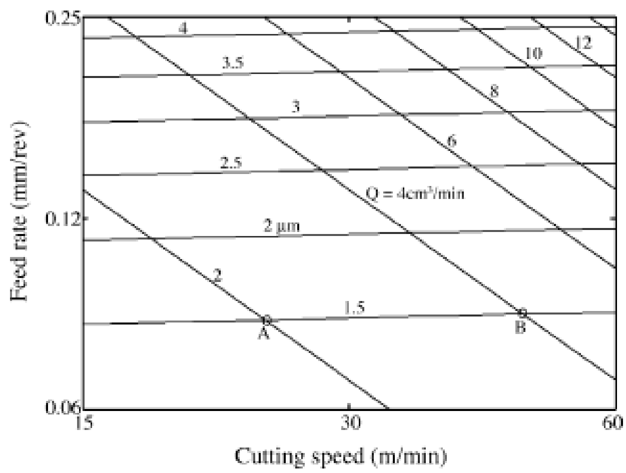

Fig.2.11 Response contours of surface roughness and metal removal Q [36]

Tugrul Ozel, Tsu-Kong Hsu, Erol Zeren [37] 2005

In this paper the effects of cutting edge geometry, work piece hardness, feed rate and cutting speed on surface roughness and resultant forces in the finish hard turning of AISI H13 steel were experimentally investigated. Four-factor and two-level fractional experiments were conducted and analysis of variance was performed. Turning operation was conducted on CNC lathe (Romi Centur 35E) at a constant depth of cut at 0.254 mm. The surface roughness was measured with a Taylor-Habson Surtronic 3+ profilometer and Mitutoyo SJ-digital surface analyzer. The cutting forces were measured with a three-component force dynamometer (Kistler Type 9121). This study shows that the effects of work piece hardness, cutting edge geometry, feed rate and cutting speed on surface roughness are statistically significant. The effects of two factor interactions of the edge geometry and the work piece hardness, the edge geometry and the feed rate, and the cutting speed and feed rate also appeared to be important. Cutting-edge geometry, work piece hardness and cutting speed are found to be affecting force components.

Z.W. Zhong, L.P. Khoo, S.T. Han [39] 2006

In this experiments Aluminium and copper were chosen as the work materials for the turning operation. A popular multi-layer construction of feed-forward neural networks was employed to produce a system that was able to predict two surface roughness parameters given the seven cutting parameters shown in Fig. 2.12.

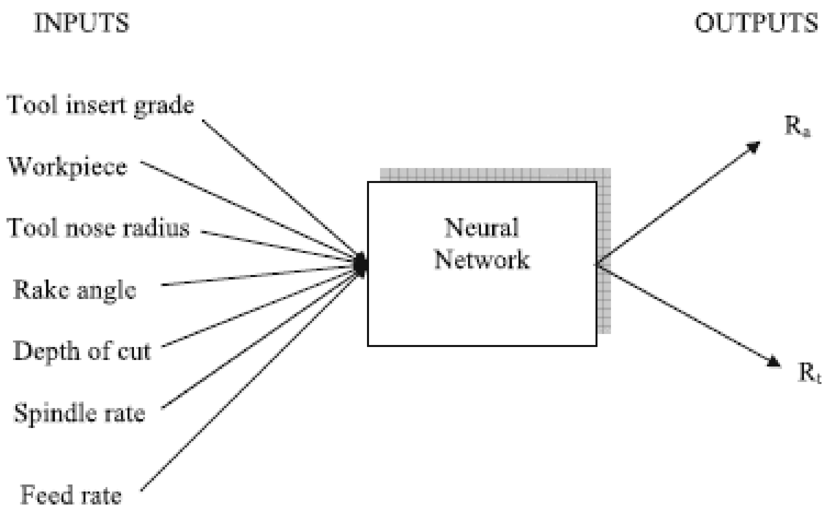

Fig. 2.12 Inputs and outputs of the network [39]

Author have collected 304 sets of data in the turning experiments, and measurements of the surface roughness were scaled into the range. 30 datasets were picked randomly to form testing data to check the network accuracy, and the remaining 274 sets were allocated to training data for training the network. The outcome proved that the network was able to predict the Ra and Rt values of the surfaces machined on this lathe as well.

E. Daniel Kirby, Zhe Zhang, Joseph C. Chen, Jacob Chen [40]2006

This paper presents an application of the Taguchi design method to optimizing the surface finish in a turning process. The control parameters for this operation included: spindle speed, feed rate, depth of cut, and tool nose radius. A total of 36 experimental runs were conducted using an orthogonal array, and the ideal combination of control factor levels was determined for the optimal surface roughness and signal-to-noise ratio. The study commence that the control factors had varying effects on the response variable, with feed rate and tool nose radius having the highest effects. The noise factors, on the other hand, were found to not have a statistically noticeable effect.

W. Grzesik, T. Wanat [41] 2006

Grzesik and Wanat have work with surface finish generated in hard turning of quenched alloy steel parts using conventional and wiper ceramic inserts. AISI 5140 steel (hardened to 60±1HRC) were used for experimental purpose. The inserts used in the experiments are as below:

a) Conventional SNGN 120408 T01020 (Fig. 2.13), tool holder CSRNR 2525M 12–IC
b) Wiper CNGA120408 T01020 WG (Fig. 2.14) , tool holder DCLNR 2525M 12-2.

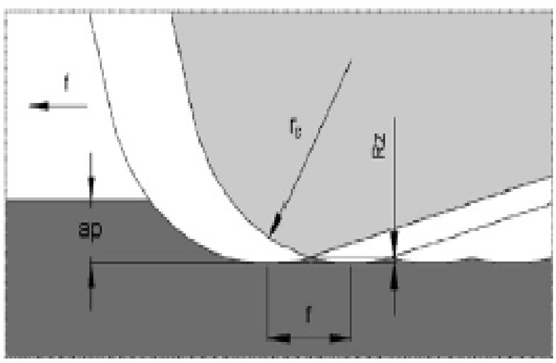

Fig. 2.13 Conventional geometry [41]

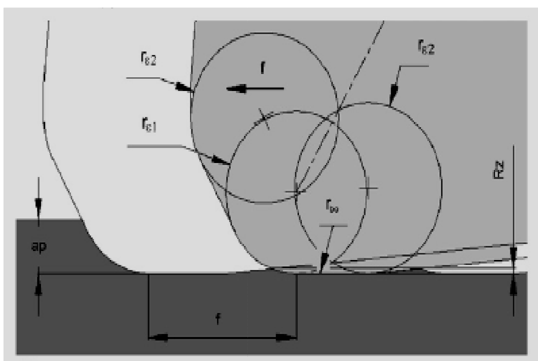

Fig. 2.14 Wiper shape [41]

In the second part of experiments, the effect of tool nose wear on the changes of surface finish was determined. After each test, part surface finish was measured with a stylus profile graph. In addition, the 3D topographic maps of the machined surfaces were produced using scanning technique. At the end it was concluded that Finish hard turning with wiper inserts give equivalent surface roughness to the effects obtained at lower feed rate during conventional operations. In this analysis this fact was documented when turning with conventional tools keeping 0.04 mm/rev feed and wiper tools using 0.1 mm/rev feed. For these cases the average values of roughness parameters are: Ra= 0.28 µm and Rz = 1.55 µm, and Ra = 0.25 µm and Rz =1.62 µm, respectively. It was observed that the Ra parameter changes similarly for both inserts used during 30 min wear tests.

A.M.A. Al-Ahmari [42] 2007

In this paper, experimental models for tool life, surface roughness and cutting force are developed with RSM and Neural Network for turning operations. Process parameters (cutting speed, feed rate, depth of cut and tool nose radius) are used as inputs to the developed machinability models. 28 numbers of experiments were carried out on turning of AISI 302 steel to evaluate the proposed models for tool life, cutting force and surface roughness. The three model building methods (RA, RSM, and CNN) are compared and evaluated using descriptive statistics. It has been establish that the CNN models are better than RA and RSM models. Also, RSM models are better that RA models for predicting tool life and cutting force models.

Ersan Aslan, Necip Camuscu, Burak Birgoren [43] 2007

The goal of this experimental work was to investigate the effects of cutting parameters on tool wear and surface roughness and to establish a correlation between them. Selected process parameters are cutting speed, feed rate and depth of cut for work material AISI 4140 steel. The turning tests were conducted on TAKSAN TTC- 630 CNC lathe. The cutting tool used with designation of SNGN120708T02020. Taguchi method was used with L_{27}. Flank wear was measured with Scherr Tumico 98/0001 toolmaker's microscope. Surface roughness measurements were performed by using a Mahr Perfhometer M1. The cutting speed is the only statistically significant factor influencing the tool wear. Two interactions, cutting speed-feed rate and feed rate-axial depth of cut, have statistically significant influence on the surface roughness:

Julie Z. Zhang, Joseph C. Chen, E. Daniel Kirby [44] 2007

This paper presents a study of the Taguchi method to optimize surface quality in a CNC face milling operation. This study integrated feed rate, spindle speed and depth of cut as control factors. An orthogonal array of L_9 (3^4) was used; ANOVA analyses were carried out to identify the significant factors affecting surface roughness and the optimal cutting combination was determined by seeking the best surface roughness (response) and signal-to-noise ratio. The investigational outcome indicates that in this study the effects of spindle speed and feed rate on surface were larger than depth of cut for milling operation. In addition, one of the noise factors, tool wear was found to be statistically significant.

Tugrul Ozel, Yigit Karpat, Luıs Figueira, J. Paulo Davim [45] 2007

A 3^3 factorial design was used to establish the effects of cutting speed, feed rate and cutting time on resultant forces, surface roughness and tool wear in hard turning of AISI D2 steel. Experiments were performed using a high rigidly CNC lathe with 18kW spindle power. The following cutting parameters were used: cutting speed (Vc) of 80, 115 and 150 m/min, feed rates (f) of 0.05, 0.10 and 0.15 mm/rev and constant depth of cut (ap) of 0.2 mm. Mixed alumina inserts with wiper geometry and a coating with TiN Ref. GC6050 (ISO code-CNGA 120408 S01525 WH) (Fig. 2.15) were used to machining of AISI D2 tool steel. The measurement of surface roughness parameters Ra and Rt on finish turning surfaces was made by a stylus instrument. The evaluation of the flank tool wear was made by a toolmaker's microscope.

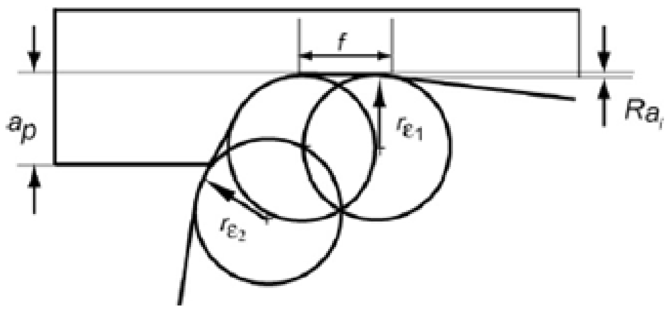

Fig. 2.15 Wiper insert design: $r_{\varepsilon 1}$ and $r_{\varepsilon 2}$ are the radii of wiper curvature [45]

The basis of using multi-radii wiper tools to higher feed rates while maintaining good surfaces finishes has been realized. Experimental results indicate that surface roughness Ra values as low as 0.18 - 0.20 µm are attainable with wiper tools. In general, low feed rates provided better tool life and better surface finishes was obtained at the lowest feed rate and highest cutting speed combination. Best tool life was obtained in lowest feed rate and lowest cutting speed combination as expected.

M. Nalbant, H. Gokkaya, G. Sur [46] 2007

In this study, the Taguchi method is used to find the best possible cutting parameters (Insert radius, Feed rate and Depth of cut) for surface roughness in turning. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in turning operations of AISI 1030 steel using TiN coated tools. The experimental results state that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel.

Dilbag Singh., P. Venkateswara Rao [47] 2007

In this study, the four parameters namely cutting speed, feed, effective rake angle and the nose radius of the cutting tool were chosen for the experimentation. Based on a (3^4) full factorial design, a total of 81 experiments, each having a combination of dissimilar levels of factors. A high precision NH-22 HMT lathe was used for experimentation. The work piece material (AISI 52100) was heat treated to get 58±02 HRC. This material is used for the manufacturing of the ball and roller bearings. Surface finish of the work piece materials was measured by Talysurf6. In this investigation, mixed ceramic inserts were used in the experiments, were SNGA1204 r S02θ. Figure 2.16 (a, b, c) shows 3D surface contours for different nose radius. The experimental work of this study indicate that the parameters cutting velocity, feed, effective rake angle and nose radius are the primary influencing factors, which affect the surface finish. The results also indicate that feed is the main factor affecting the surface roughness, followed by the nose radius, cutting velocity and effective rake angle.

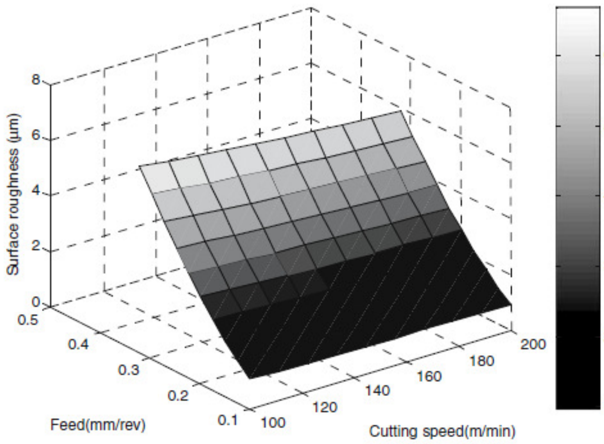

Fig. 2.16 (a) Effective rake angle = 6^0, nose radius = 0.4 mm [47]

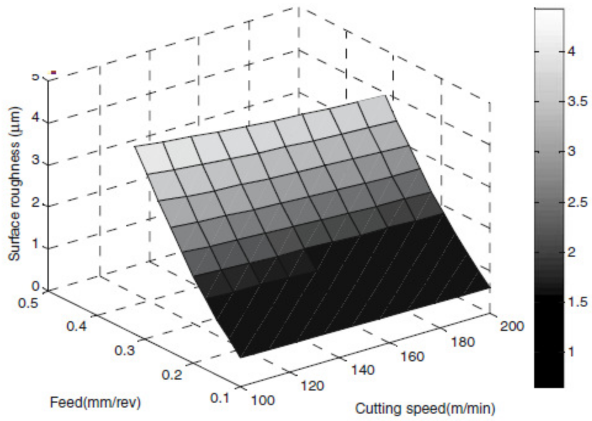

Fig. 2.16 (b) Effective rake angle = 6^0, nose radius = 0.8 mm [47]

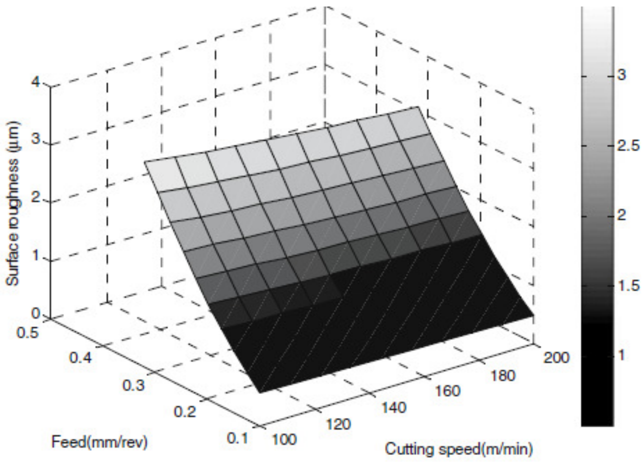

Fig. 2.16 (c) Effective rake angle = 6^0, nose radius = 1.2 mm [47]

Jenn-Tsong Horng, Nun-Ming Liu, Ko-Ta Chiang [48] 2008

The main purpose of this experiment is to get the correlation between the machining parameters (speed, feed rate, depth of cut and tool corner radius) and the machinability performance, including tool wear and surface roughness. The turning experiments were carried out on a Vcenter-55/70 CNC lathe with Hadfield steel (SCMnH11) material. Measurements of the surface roughness were performed by using a Mitutoyo SurfTest-402. The flank wear was measured with TM-505, Mitutoyo toolmaker's microscope. RSM was employed for modelling and analysis of machining parameters in the hard turning process in order to obtain the machinability performances of flank wear and surface roughness. The results of ANOVA and the conducting verification experiments have proved that the mathematical models of the flank wear (VBmax) and surface roughness (Ra) fit and predict values of the flank wear and surface roughness which is close to those readings recorded experimentally with a 95% confident interval.

D.I. Lalwani, N.K. Mehta, P.K. Jain [49] 2008

The purpose of this experiment is to observe cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel (equivalent to 18Ni (250). NH22 (HMT, India) lathe equipped with specially designed experimental setup was used for experimentation. The cutting forces were measured using Kistler® piezoelectric dynamometer (model 9257B) mounted on specially designed fixture. The measurements of surface roughness (Ra) were made on the Veeco WYKO NT1100 surface profilometer. The machining experiments were conducted based on response surface methodology (RSM) and sequential approach using face cantered central composite design. Fig. 2.17 shows edge preparations in CBN and ceramic cutting tools.

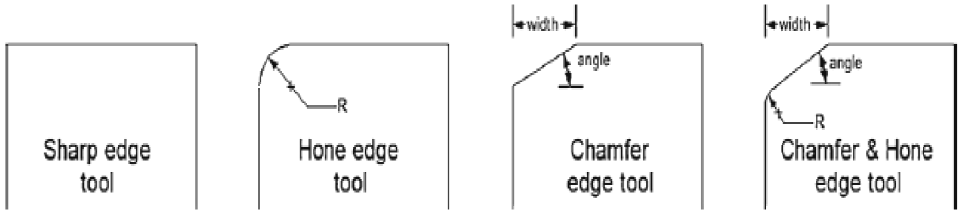

Fig. 2.17 Type of edge preparations used in CBN and ceramic cutting tools [49]

From the experiments it was concluded that linear model is fitted for feed force, thrust force and cutting force whereas quadratic model is fitted for surface roughness. Feed rate provides primary contribution and influences most significantly on the surface roughness. The interaction between feed rate and depth of cut, quadratic effect of feed rate and interaction effect of speed and depth of cut provide secondary contribution to the model.

M. Joseph Davidson, K. Balasubramanian, G.R.N. Tagore [50] 2008

Authors have used Box-Behnken design (17 experiments) for developing the mathematical model for surface roughness attained by the flow-formed AA6061 tube. RSM was applied to develop the mathematical model. The input parameters and their levels are given in Table 2.4. Figs. 2.18-2.20 shows 3D surface graphs for different conditions. Finally it was concluded that RSM model can successfully relate the above process parameters with the response, surface roughness. The verifying test has shown that the predicted value agrees with the experimental evidence.

Table 2.4 Input parameters and their levels [50]

Sr. No.	Parameter	Low level	High level
1	Feed (mm/min)	25	75
2	Speed (rpm)	250	350
3	Coolant (l/min)	1.2	3.6

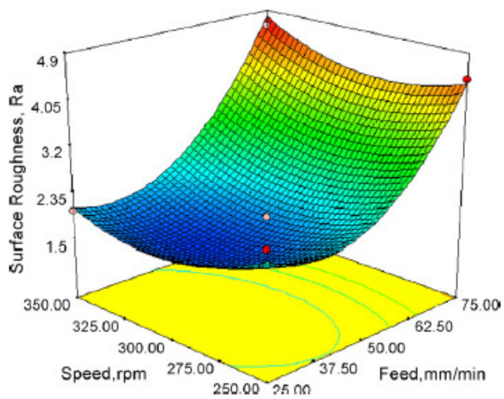

Fig. 2.18 3D surface graph for the surface roughness at Coolant = 2.4 l/min, as speed and feed varies [50]

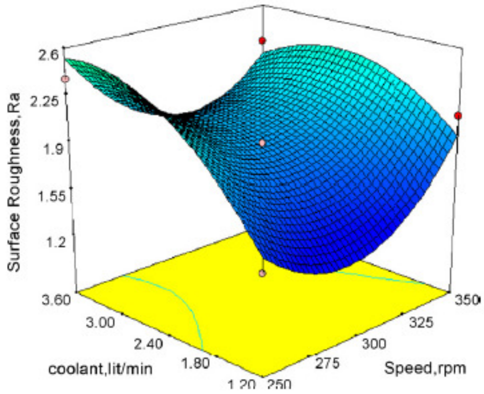

Fig. 2.19 3D surface graph for the surface roughness at feed = 50mm/min as speed and coolant varies [50]

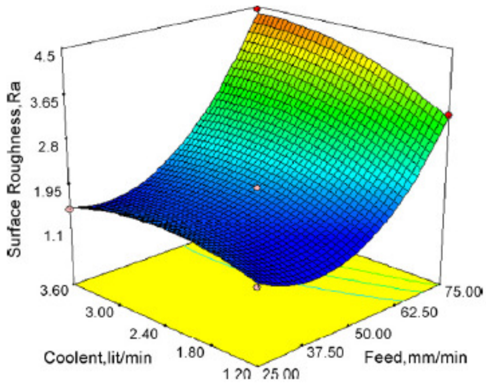

Fig. 2.20 3D surface graph for the surface roughness at speed = 300 rpm as coolant and feed varies [50]

J. Paulo Davim, V.N. Gaitondeb, S.R. Karnik [51] 2008

Authors have selected Taguchi's L_{27} (3^{13}) orthogonal array for experimentation. Cutting parameters are feed rate, cutting speed and depth of cut for this work and consisting 27 experiments to be performed under different combinations of the factor levels. The machining tests were conducted on a conventional lathe with a 6 kW power. The free machining steel (9SMnPb28k) work piece material and TPUN 160308 P10 (ISO) cemented carbide inserts were used throughout the experiments. The surface roughness was measured at three equally spaced locations around the circumference of the work pieces and the average was taken as the process response. A multi-layer feed forward ANN was employed for this purpose, which was trained by error back-propagation algorithm. The surface roughness parameters are highly responsive to both cutting speed and feed rate. On the other hand, depth of cut has the least effect. The surface roughness has a inclination to reduce with the increase in cutting speed and also with the reduction in feed rate. The smallest surface roughness results with the combination of low feed rate and high cutting speed.

G. Petropoulos, F. Mata, J. Paulo Davim [52] 2008

Unreinforced polyetheretherketone (PEEK) and reinforced polyetheretherketone with 30% of carbon fibers (PEEK CF 30) and 30% of glass fibers (PEEK GF 30) were used for tests. The experiments were carried out in extruded work pieces using a polycrystalline (PCD) insert tool (DCMW 11T3 04FPDC10) and cemented carbide (K15) tool (DCMW 11T304H13A). A CNC lathe ‘‘Kingsbury MHP 50’’ of 18 kW was used to perform the experiments. The surface roughness was measured with a Hommel tester T1000 profilometer. In view of all three PEEK's examined increase in feed causes significant increase in all the surface roughness parameters introduced. Increase of cutting speed is favorable, as decreases roughness but only slightly. The presence of glass fibers tends to increase roughness more than carbon fibers. The polycrystalline diamond tool provides smaller values of roughness, especially for values of feed rate >0.1 mm/rev.

K. Palanikumar [53] 2008

Palanikumar have used Taguchi's orthogonal array in the design of experiments (DOE) for minimizing the surface roughness in machining glass fibre (GFRP). The three cutting parameters selected for the present investigation is cutting speed, feed and depth of cut. All the turning experiments were performed in a geared lathe. The tool holder used for the turning process was a WIDAX tool holder PC LNR 1616 K12 and the tool material used for the study was PCD tool. The surface roughness was measured by using a Surtronic 3+ stylus type instrument manufactured by Taylor Hobson. Based on the experimental results feed is the main parameter for surface roughness followed by the cutting speed. Depth of cut shows minimal effect on surface roughness compared to other parameters. For getting good surface finish on the GFRP work piece high cutting speed, high depth of cut and lower feeds are chosen.

N. Muthukrishnan, J. Paulo Davim [54] 2009

In this investigational work, MMCs of type A356/SiC/20p was used for the experimental work. A medium duty lathe with 2 kW spindle power was used to perform the experiments. The CNMA 120408 inserts with PCLNR 25 X 25 M12 tool holders with

PCD were used to turn the billets of 150 mm diameter. The microstructure of the work material is shown in Fig. 2.21.

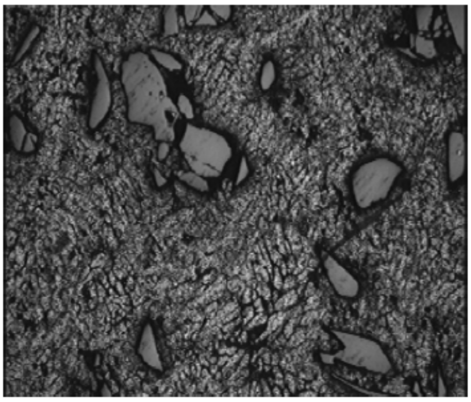

Fig. 2.21 Microstructure of the Al–SiC (20 p) MMC [54]

The average surface finish (Ra) was measured with surface roughness tester Mitutoyo Surf test 301. ANOVA and ANN two modelling techniques were used to predict the surface roughness. In ANOVA, it is revealed that the feed rate has peak physical as well as statistical influence on the surface roughness after the depth of cut and the cutting speed. The results of ANN show close matching between the model output and the directly measured surface roughness. ANN methodology consumes lesser time giving higher accuracy. Hence optimization using ANN is the most valuable method compared with ANOVA.

M. Cemal Cakir, Cihat Ensarioglu, Ilker Demirayak [55] 2009

Two CNMG 120408 carbide inserts, having completely the same geometry and substrate but different coating layers, were used in the experimental work shown in Figs. 2.22 and 2.23. Individual experiments were conducted using 3 various cutting speeds, 3 various feed rates and 3 various cutting depths. The machine tool employed was a turning lathe of 5.5Kw with work piece material cold-work tool steel AISI P20. Using all possible combinations, 54 experiments (27 for each tool) were conducted and surface roughness values (Ra) obtained from these experiments, for both Insert 1 and Insert 2, are measured. Authors have concluded that feed rate has the greatest influence, followed by cutting speed. Higher feed rates lead to higher surface roughness values, whereas cutting speed has a contrary effect and cutting depth has no significant effect. Although the positive effect of higher cutting speeds can easily be noticed when employing CVD coated (TiCN +Al2O3 +TiN) Insert 1, surface roughness values obtained when employing PVD coated (TiAlN) Insert 2 are lower.

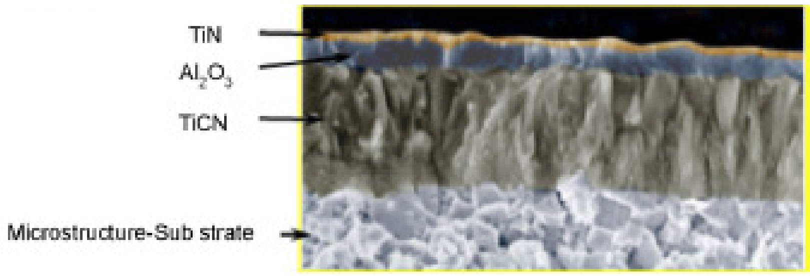

Fig. 2.22 Coating layers of Insert 1 [55]

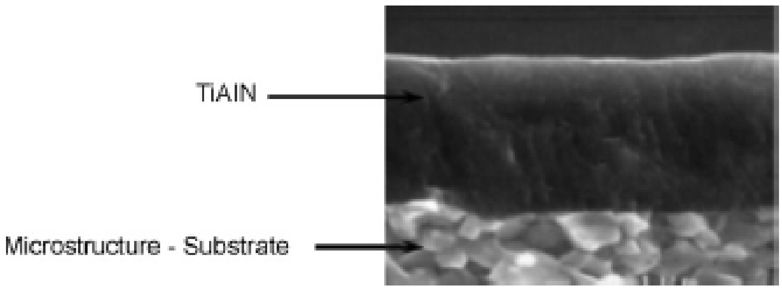

Fig. 2.23 Coating layer of Insert 2 [55]

M. Anthony Xavior, M.Adithan [56] 2009

Objective of this work is to learn the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel. A Centre Lathe (Kirloskar make Turn Master 40) was used for conducting the experiments. AISI 304 was used as the work material and Sandvik's carbide CNMG 12 04 08 insert was used as a tool.

Table 2.5 Critical parameters and their levels [56]

Sr. No.	Parameter	Level-1	Level-2	Level-3
1	Cutting speed (m.min)	38.95	61.35	97.38
2	Depth of cut (mm)	0.5	1	1.2
3	Feed rate (mm/rev)	0.2	0.25	0.28
4	Cutting fluid	Coconut oil	Soluble oil	Straight cutting oil

After the machining process, the insert was removed and its flank wear was measured using Mitutoyo's Tool Maker's microscope. The average surface roughness on the work piece was measured using Mitutoyo's Surftest. The experimentation for this work was based on Taguchi's design of experiments L_{27} (3^4) orthogonal array for testing. Table 2.5 shows the parameters and their levels considered for the experiments. An analysis of variance (ANOVA) was made and it was found that feed rate has greater influence on surface roughness (61.54% contribution) and cutting speed has greater influence on tool wear (46.49% contribution). Further it was found that cutting fluid has some considerable influence on both surface roughness and tool wear. In general, coconut oil was found to be a better cutting fluid than the conventional mineral oils in reducing the tool wear and surface roughness.

Durmus Karayel [57] 2009

In this work Durmus have used ANN for Prediction and control of surface roughness in CNC lathe. The cutting tests have been carried out on a CNC lathe (Tezsan Company). First, all of the test parts have been machined by fine turning under the same cutting conditions. The surface roughness values of (Ra), Rz, and Rmax have been measured with a Hommel Surface Roughness Tester (T20). It was concluded that an actual modelling approach using an ANN for prediction and control of surface roughness in turning has been developed. The feed rate is a leading factor and the surface roughness increases rapidly with the increase in feed rate. The effect of depth of cut on surface roughness is not regular and has a variable character. The cutting speed has a critical value for which the best surface quality can be achieved.

V. N. Gaitonde, S. R. Karnik, Luis Figueira, J. Paulo Davim [58] 2009

In this work authors have used 3^3 full factorial design to explore the response surface. Thus, 27 experiments based on full factorial design were planned. Turning experiments were performed on a high rigidity 'Kingsbury MHP 50' CNC lathe. In the present investigation, the work bar of high chromium AISI D2 cold work tool steel is used. A 'Kistler®' piezoelectric dynamometer (model 9121) was used to obtain three different components of forces. The measurement of the surface roughness on turning surfaces was made by a 'Hommelwerke T1000' type profilometer. The evaluation of the flank tool wear was made by a 'Mitutoyo TM-500' tool makers' microscope. Based on the experimental results the machining force is highly sensitive to feed rate variations at all values of cutting speed and machining time. The power is highly sensitive to feed rate variations as compared to cutting speed. The combination of low feed rate, less machining time, and high cutting speed is necessary for minimizing the surface roughness. The maximum tool wear occurs at a cutting speed of 150m/min for all values of feed rate.

M. Vijaya Kini, A.M. Chincholkar [59] 2010

Aim of the paper is to develop of an empirical model for turning GFRP utilizing factorial experiments. A two-level full factorial design was used to conduct the experiments. Thus, the design matrix has $2^4 = 16$ experiments. The important process parameters that affect the surface roughness and MRR are cutting speed, feed rate, depth of cut and tool nose radius. Dry machining with inserts (VCMT 16T304 and VCMT 16T312) were carried out on a PSG A141 geared lathe. The surface texture was measured using SURTRONIC 3+ surface roughness tester and the profiles analysed using Talyprofile software to obtain the Ra value (Fig. 2.24). The results obtained were analyzed using Minitab R14 software. Table 2.6 shows the coded and encoded values of the parameters.

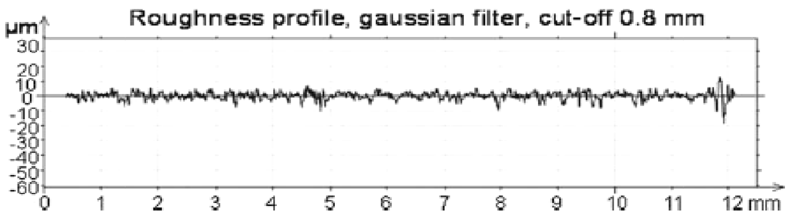

Fig. 2.24 Surface roughness profile [59]

Table 2.6 Factors and their levels [59]

Factor	Level (coded)			Level (uncoded)		
Cutting speed (m/min)	-1	0	1	59.94	92.072	133.204
Feed rate (mm/rev)	-1	0	1	0.1	0.25	0.4
Depth of cut (mm)	-1	0	1	0.1	0.15	0.2
Tool nose radius (mm)	-1	0	1	0.4	0.8	1.2

For the surface roughness, the feed rate is the major influencing factor on the roughness, followed by the depth of cut. For material removal rate, the depth of the cut is the most important influencing factor on the roughness, followed by the tool nose radius

H. H. Shahabi, M. M. Ratnam [60] 2010

The surface roughness of turned parts is usually measured using the conventional stylus type instruments. Machine vision methods of roughness measurement are being developed global due to their inherent advantages, including noncontact measurement, high information content, rapid measurement, and surface measurement capability. In this paper, an alternative method of roughness measurement using the 2-D profile extracted from an edge image of the work piece surface is proposed. Comparison with a stylus type instrument shows a maximum difference of 10% in the measurement of average roughness Ra using the vision method.

Nikolaos I. Galanis, Dimitrios E. Manolakos [61] 2010

Nikolas, Dimitrios and Manolakos have used 2^3 factorial designs which have another 21 points in the middle, edges and faces of the representation cube, as shown Fig. 2.25. The work pieces, manufactured in a CNC lathe OKUMA Lb 10II, were made of AISI 316L steel. A coated cutting tool from SECO specification: DNMG 110402-M3 with TP 2000 coated grade was used for the manufacturing process. The measurement of the surface roughness on turning surfaces was made by a Roughness tester.

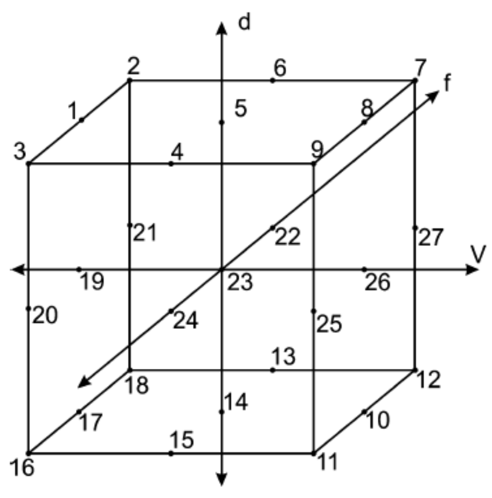

Fig. 2.25 Central composite design for three factors [61]

Finally authors have given surprised finish. The established equations confirm that the depth of cut was a main influencing factor on the surface roughness. It increased with increasing the depth of cut and the feed rate, respectively, but it decreased with increasing the cutting speed. Among the other parameters, the feed rate was found to be more insensitive than the speed. First-order and second-order model predicting equations for surface roughness have been developed using RSM.

Nikos C. Tsourveloudis [62] 2010

Objective of the experiments is Predictive Modeling of the Ti6Al4V Alloy Surface Roughness through RSM and fuzzy logic system through the adaptive Neuro fuzzy inference system (ANFIS). The design of experiments follows the Taguchi method. The factors, for turning operation and given cutting tools and conditions, are: the feed rate, the chuck rotation or turning speed and the cutting depth. All effort has been carried out on a TOS SN32 lathe. The cutting tools used are coated carbide inserts. The present study addressed this problem by developing: Regression-based prediction equations utilizing the RSM and Neuro-fuzzy models through the ANFIS architecture. The feed rate has been verified as the most important machining parameter for the surface roughness of Ti6Al4V. ANFIS predicts the Ra of Ti6Al4V better than the RSM.

Suleyman Neseli, Suleyman Yaldız, Erol Turkes [63] 2011

Purpose of this work is to study the influence of tool geometry on the surface finish obtained in turning of AISI 1040 steel. In this study, L_{27} Taguchi standard orthogonal array is taken as the experimental design. The turning experiments were carried out in dry cutting conditions using Harrison M300 lathe. In this study, three factors were studied and their low middle–high levels are given in Table 2.7.

Table 2.7 Independent variables and levels for model [63]

Factor	Unit	Level 1	Level 2	Level 3
Nose radius (r)	mm	0.4	0.8	1.2
Approach angle (k)	Degree(◦)	60	75	90
Rake angle (γ)	Degree(◦)	-9	-6	-3

The cutting tools used were manufactured by Bohler Inc., with the ISO designation of CNMG 120404-BF, CNMG 120408-BF, CNMG 120412-BF (800 Rhombic inserts). After the experiments, Mahr Perthometer M1 was used for measuring the surface roughness. The results of the research are: Tool nose radius is the most important factor on surface roughness with 51.45% contribution. Also, approach angle and rake angle are significant factors on surface roughness with 18.24% and 17.74% contribution respectively. Using response optimization show that the optimal combination of machining parameters are (0.4 mm, 600, -30) for tool nose radius, approach angle and rake angle, respectively.

Ilhan Asilturk, Harun Akkus [64] 2011

The aim of this paper is to obtain optimal turning parameters (cutting speed, feed rate and depth of cut) for minimum on surface roughness, for turning hardened AISI 4140 steel with Al2O3 and TiC-coated carbide tools. The Taguchi method and L_9 Orthogonal array were used to reduce number of the experiments. The investigational studies were carried out on a Mori Seiki NL 2500 CNC Lathe. The surface roughness was measured using a Mitutoyo SJ-301P portable device. Fig. 2.26 shows the experimental arrangement.

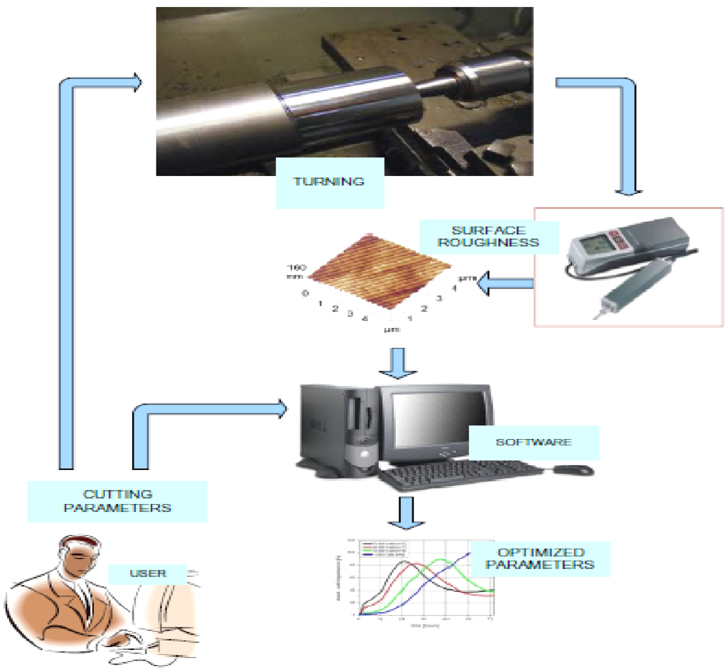

Fig. 2.26 Experimental scheme [64]

The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important.

Ilhan Asiltürk, Mehmet Cunkas [65] 2011

In this paper full factorial experimental design is implemented to investigate the effect of the cutting parameters (i.e. cutting speed, feed rate, and depth of cut) on the surface roughness. The multiple regression models are tested by aiding the analysis of variance (ANOVA). Multilayer perception (MLP) architecture with back-propagation algorithm having two different variants is used in neural network Data sets are from experiments conducted on a CNC turning machine in the laboratory of the Selcuk University, Konya, Turkey. Single insert was used in the experiments for machining of AISI 1040 steel. A National Instruments portable E Series NI DAQCard-6036E with maximum acquisition rate of 200,000 samples per second and 16 channels, data acquisition card was used to transmit the data to PC. Surface roughness (Ra) was measured with Surface Roughness Tester Mitotoyo (SJ-301). Conclusions can be drawn from the present study are: The feed rate is the major factor affecting the surface roughness, followed by cutting of depth and cutting speed.

Esteves Correia, J. Paulo Davim [67] 2011

A CNC lathe ‘‘Kingsbury MHP 50’’ with 18 kW was used to perform the research. The experiments were carried out in carbon steel AISI 1045 pre prepared work pieces with six tracks with a diameter of 51 mm and a length of 119 mm (Fig. 2.28), using a cemented carbide conventional (CNMG 120404 PF and CNMG 120408 PF) and wiper (CNMG 120404 WF and CNMG 120408 WF) tools. Fig. 2.27 shows straight and wiper (multi-radii) geometry. The plan of tests were developed with lubrication conditions and contemplate the nine combinations between three values of cutting speed and three values of feed rate (low, medium and high).

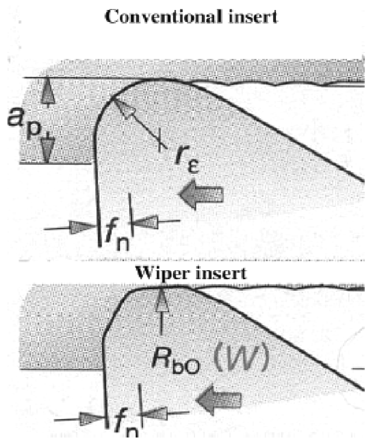

Fig. 2.27 Comparison of inserts with conventional and wiper (multi-radii) geometry [67]

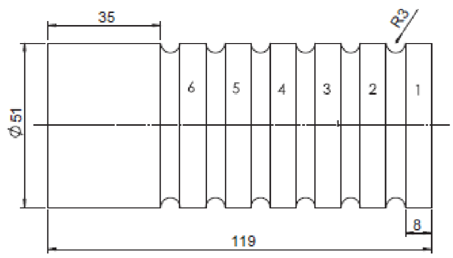

Fig. 2.28 Pre prepared work pieces in AISI 1045 used in turning tests [67]

Finish machining with wiper inserts provide a similar roughness when compared with machining with a low feed rate using conventional inserts. With wiper inserts and high feed rate (0.25 mm/rev) is possible to obtain machined surfaces with <0.8 µm of Ra.

Ahmad Hamdan, Ahmed A. D. Sarhan, Mohd Hamdi [68] 2012

Taguchi method with orthogonal array L_9 (3^4) was used in this experiment in high speed machining of AISI-304. It consists of nine experiments with four different factors.

Table 2.8 Factors and levels used in experiments [68]

Factor	Experimental condition levels		
	1	2	3
A:Cutting speed (m/min)	300	350	400
B:Feed rate (mm/tooth)	0.05	0.1	0.15
C:Axial depth of cut (mm)	0.5	0.75	1
D:Lubrication mode	Dry	Flood	MQL

The factors and levels are specified in Table 2.8. The machine used was a vertical type-machining center (Mitsui Seiki VT3A). The KORLOY carbide insert with an ISO designation of APXT 11T3PDSR-MM (coated with titanium aluminium nitride) is used. The cutting forces were measured using a Kistler three-axis dynamometer (type 9255B). To measure the machined work piece surface roughness Ra, a portable profilometer M1 perthometer (Mahr, Germany) is used. Based on experiments, feed rate is found to be more significant followed by the cutting speed and the depth of cut, while, the lubrication mode was found to be statistically insignificant.

S. Ramesh, L. Karunamoorthy, K. Palanikumar [69] 2012

The experiment was performed by using Taguchi's L_{27} orthogonal array. The machining parameters considered for the experiments were: cutting speed, feed, and depth of cut. Commercial Ti–6Al–4V (grade-5) alloy was used in the present investigation. Fig. 2.29 shows the microstructure of the titanium alloy for this investigation. The experimental studies were carried out on a conventional high speed lathe. In the present investigations, the cutting tool used is TaeguTec RCMT 10T300 – MT TT3500 round insert. The round insert used in the investigation is shown in Fig. 2.30. Surface roughness measuring instrument (Talysurf 50) was used for the surface roughness measurement. The cutting tool and chip formations were studied under scanning electron microscopy (SEM).

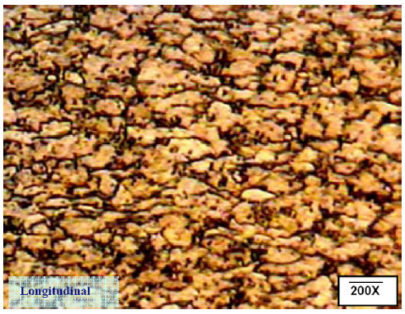

Fig. 2.29 Microstructure of Ti–6Al–4V [69]

Fig. 2.30 CVD coated carbide insert [69]

In this work Taguchi ANOVA analysis was performed. The most affecting parameter was identified as the feed. The order of significance was feed, followed by depth of cut and cutting speed.

Hamdi Aouici, Mohamed Athmane Yallese, Kamel Chaoui, Tarek Mabrouki, Jean-Francois Rigal [70] 2012

Turning experiments were performed in dry conditions using a lathe type SN 40C. The work piece material was AISI H11, hot work steel. Standard designation of cutting inserts are SNGA12 04 08 S01020 and it is manufactured by Sandvik company. The three components of the cutting forces; feed force (Fa), thrust force (Fr) and tangential force (Fv) were recorded using a standard quartz dynamometer (Kistler 9257B). Surface roughnesses of turned parts are obtained by means of a Mitutoyo Surftest SJ-201. Designing of experiment was based on Box–Behnken Designs (BBDs. The levels of the four factors or machining parameters are reported in Table 2.9. The experimental design consists of 29 runs. In order to investigate the influences of machining parameters on the surface roughness (Ra), response surface are drawn in Figs. 2.31 and 2.32.

Table 2.9 Assignment of the factor levels [70]

Level	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Work piece hardness (HRC)
1	120	0.08	0.15	40
2	180	0.12	0.3	45
3	240	0.16	0.45	50

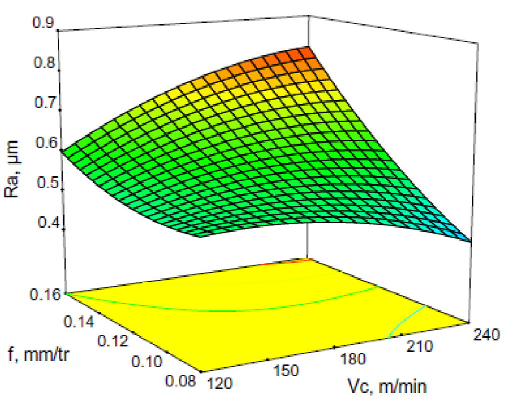

Fig. 2.31 Effect of cutting speed and feed [70]

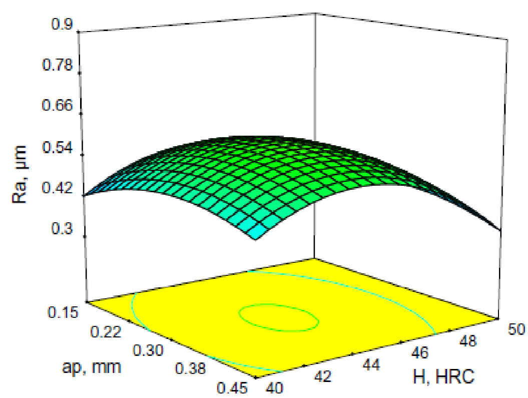

Fig. 2.32 Effect of hardness and DOC [70]

This study shows that the feed rate and work piece hardness have significant statistical influences on the surface roughness. The effects of two-factor interactions feed rate and depth of cut, cutting speed and work piece hardness, cutting speed and feed rate, work piece hardness and feed rate, and the products (H2 and ap2) appeared also to be important. The best surface roughness was achieved at the lower feed rate and the highest cutting speed

Catalin Fetecau, Felicia Stan [71] 2012

This paper presents an investigation on turning of PTFE composites using a polycrystalline diamond tool in order to analyze the effect of the cutting parameters and insert radius on the cutting force and surface roughness. Two types of PTFE composites, such as reinforced polytetrafluoroethylene with 32% carbon and 3% graphite (PTFE CG 32-3) and 15% regenerated graphite (PTFE GR 15) were used for the machining tests. The cutting tests were conducted on a universal lathe model SN400. The surface roughness was measured using a Taylor Hobson Profilometer Surtronic 3+. The Taguchi methodology (orthogonal array L_{27}) was used for the design of the experiment during turning. Process variables and their levels are shown in Table 2.10.

Table 2.10 Process variables and their levels [71]

Factor		Cutting force			Surface roughness		
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
A	Feed rate (mm/rev)	0.053	0.167	0.25	0.053	0.106	0.25
B	Depth of cut (mm)	0.5	1.5	2	0.5	1.5	2
C	Cutting speed (m/min)	51.02	128.58	163.28	51.02	128.58	163.28
D	Insert radius (mm)	0.4	0.8	1.2	0.4	0.8	1.2

Statistical results indicate that the cutting force is significantly influenced by feed rate and depth of cut. The cutting force increases with the increase of feed rate and depth of cut, respectively. The surface roughness is significantly influenced by the feed rate and insert radius. The surface roughness increases with the increase of the feed rate, and decreases with the increase of insert radius. Although the effect of cutting speed and depth of cut is less significant.

R. Suresh, S. Basavarajappa b, G.L. Samuel [72] 2012

In this paper Taguchi's L_{27} (3^{13}) orthogonal array was chosen for plan of experiments. Computer numerically controlled (CNC) lathe was employed to conduct the experiments. The coated carbide inserts of ISO geometry CNMG 120408 were used throughout the investigation. During the machining of AISI 4340 steel, the cutting force (Fc), radial force (Ft) and feed force (Fr) were measured using a piezo-electric dynamometer (Kistler model 9263A) which was connected to charged amplifiers and a personal computer through an analog to digital converter card. The surface roughness values were taken as an arithmetic surface roughness (Ra). 3D Surface plots for the surface roughness are shown in Fig. 2.33.

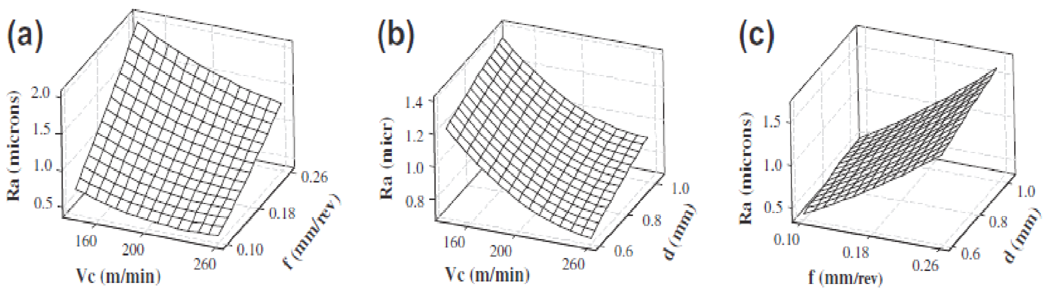

Fig. 2.33 3D surface plots for surface roughness [72]

The feed rate has highest physical as well statistical influence on the machining force to perform the machining operation followed by depth of cut and cutting speed. The feed rate has highest influence on surface roughness, cutting speed, and followed by depth of cut. The surface finish was improved as cutting speed was increased and deteriorated with feed rate. The optimum parameter setting for better surface finish is obtained at a higher cutting speed with low feed.

A short summary of a few researchers having worked on the surface roughness is given in Table 2.11.

Table 2.11 Factors affecting on surface roughness and major investigators

Investigators	Trials	Major Factors Studied	Material used	Methodology	Remarks
I.A. Chaudhary (1997)	24	Cutting speed, Feed, Depth of cut	EN-24 T	Factorial design	Authors have used Factorial design and RSM approach and found that second order model is more adequate.
W.H. Yang (1998)	9	Cutting speed, Feed, Depth of cut	S 45C	Taguchi method	Authors have worked with Taguchi method for optimization, improvement of tool life & roughness were 25%.
J.D.Thiele (1999)	36	Work Hardness, Edge geometry, Feed	AISI 52100 steel	Factorial design	It was found that Cutting edge geometry and hardness x edge geometry interactions are more significant.
J.P. Davim (2001)	27	Cutting speed, Feed, Depth of cut	Free Mach. steel	Taguchi method	It was concluded that cutting speed has influence on roughness followed by feed. Depth of cut has no significant effect.
C.X. Fang (2002)	16	Hardness, Feed, Point angle, Depth of cut, Cutting speed	8620 steel and Al	2^{5-1}fractional factorial	Authors have used more nos. of factors. Minitab software was used for computational work
I. Puerta Arbizu (2003)	18	Cutting speed, Feed, Depth of cut	Steel	Factorial design	It was found that feed and depth of cut have negative influence. Optimum value of speed provides best surface roughness.
C.X .Fang (2003)	32	Hardness, Feed, Nose radius, Depth of cut, Cutting speed	8620 steel and Al	Factorial design	Authors have done comparison of RA and CNN for 8620 steel and Aluminium.
M.Y.Noordin (2004)	16	Cutting speed, Feed, SECA	AISI 1045 steel	RSM	CCD used. Feed is the most significant factor. $SECA^2$, feed and SECA interaction also affect on Roughness.
Tugrul Ozel (2005)	16	Hardness, Edge geometry, Cutting speed, Feed	AISI H13 steel	Factorial design	Authors have used ANN and Regression analysis to predict roughness and tool wear with CBN inserts.

Yusuf Sahin (2005)	18	Cutting speed, Feed, Depth of cut,	Mild steel	Factorial design	CCD used. It was seen that feed rate and cutting speed is significant while depth of cut is insignificant.
M.A. Dabnum (2005)	12	Cutting speed, Feed, Depth of cut	Glass Ceramic	Factorial design	Author have used Dual response contour for M.R.R and surface roughness. Feed is the main factor followed by speed and depth of cut.
E.D. Kirby (2006)	36	Cutting speed, Feed, Depth of cut, Nose radius	Aluminium	Taguchi method	Authors have used Taguchi method with four control parameter. Feed rate and tool nose radius having highest effect on Ra.
A.M.A Al Ahmari (2007)	28	Cutting speed, Feed, Depth of cut, Nose radius	AISI 302 steel	RSM,CNN	Authors have concluded that CNN is better than RA and RSM for predicting models.
Ersan Aslan (2007)	27	Cutting speed, Feed, Depth of cut	AISI 4140 steel	Taguchi method	Authors have used Taguchi method for the performance of flank wear and surface roughness.
Dilbag Singh (2007)	81	Cutting speed, Feed effective rake angle , Nose radius	AISI 52100 steel	Factorial design	Authors have used 3^4 full factorial design. Feed is the main factor followed by nose radius, speed and effective rake angle
Jenn-Tsong Horng (2008)	30	Cutting speed, Feed, Depth of cut, Nose radius	Hadfield steel	Factorial design	In this paper CCD and ANOVA used for flank wear and roughness. Sequential approximation optimization is used for optimum value of machining parameters.
D.I. Lalwani (2008)	28	Cutting speed, Feed, Depth of cut	MDN250 Steel	RSM	Authors have worked with CCD and RSM to predict cutting forces and surface roughness. Feed rate is most significant factor.
M.J. Davidson (2008)	17	Cutting speed, Feed ,Coolant	AA6061 Alloy	RSM	It was concluded that feed rate is most significant factor. Roughness was found to decrease with decrease in amount of coolant.
K .Palanikumar (2008)	27	Cutting speed, Feed, Depth of cut	GFRP	Taguchi method	Authors concluded that for achieving good surface finish high cutting speed, high depth of cut and lower feed is preferred.
V.N. Gaitonde (2009)	27	Cutting speed, Feed, Machining time	AISI D2 steel	Factorial design	It was found that R_a reduced at lower feed rate and machining time with higher speed while max. tool wear at 150 m/min.

M .Vijay Kini (2010)	16	Cutting speed, Feed, Depth of cut, Nose radius	GFRP	Factorial design	Authors have studied effect of M.R.R. and Roughness on GFRP. Used overlaid contours for both parameters.
N. I. Galanis (2010)	27	Cutting speed, Feed, Depth of cut	AISI 316L	Factorial design	It was conclude that Depth of cut was the most significant factor on surface roughness followed by feed rate and cutting speed. This conclusion is different than other researchers work.
Nikos C. Tsourveloudis (2010)	32	Cutting speed, Feed, Depth of cut	Titanium alloy	RSM	Authors have used RSM and ANFIS for prediction of Titanium alloy, ANFIS predicts surface roughness with less error.
Suleyman Neseli (2011)	27	Nose radius, Approach angle, Rake angle	AISI 1040 steel	Taguchi method	Authors have used Response optimization. Tool nose radius is the most significant factor on roughness (51.45%).
Ilhan Asilturk (2011)	9	Cutting speed, Feed, Depth of cut	AISI 4140 steel	Taguchi method	It was concluded that feed rate was the main influencing factor on Ra and Rz, f x v and d x v are significant parameters.
Ahmad Hamdan (2012)	9	Cutting speed, Axial depth of cut, Lubrication mode	AISI 304 steel	Taguchi method	Result shows that 25.5% and 41.3% improvement in cutting force and surface roughness with this method.
S. Chinchanikar (2013)	20	Cutting speed, Hardness, feed, Depth of cut	AISI 4340 steel	ANOVA RSM	Higher cutting forces are required for machining harder material. Cutting forces get affected mostly by depth of cut followed by feed. Surface roughness affected significantly at higher feed and depth of cut.
D. Philip Selvaraj (2014)	9	Cutting speed, Feed,	ASTM A 995 grade 5A and 4A DSS	Taguchi Method	Feed rate is the more significant parameter influencing the surface roughness and cutting force. The cutting speed was identified as the more significant parameter influencing the tool wear. The predicted results are found to be closer to exp. Results within 8% deviations.
***Present work**	81	Cutting speed ,Feed, Depth of cut, Nose radius	AISI 1040, AISI 410, M.S. and Al.	Full factorial design, RSM, Optimization	Discussed in the thesis.

2.3 Statement of problem

Previously, most published studies on turning centre show the tendency to seek effect of cutting conditions like cutting speed, feed rate and depth of cut on surface roughness as well as less number of trials (Table 2.11). Present study seeks to find out the effect of above parameters and cutting geometry such as tool nose radius on the surface roughness value and 81 numbers of experiments with different materials like AISI 1040, AISI 410, Mild steel and Aluminium with optimization of cutting parameter for obtaining best surface roughness.

Also, author has worked on structure analysis of machine tool components for turning center such as Bed, Saddle and Head for different cutting conditions. Now, for the investigations on turning centre two problems are considered.

(1) Structure analysis (FEA)

(2) Investigation on cutting parameters for turning operations

- Regression Analysis
- Optimization of cutting parameters by RSM

2.3.1 Structure analysis (FEA)

The limitations of physical modal techniques have led to the development of mathematical model representing a variety of mechanical structure [1, 3 and 6]. In the mathematical model, the first step is to sub divide the real structure in to simple elements such as beam, shell, plate, solid etc. These elements being inter connected at specified nodal points only. Then the relation between the forces and displacement at these nodal points are then derived in the form of element matrices, the manipulation of these element matrices giving the required information about the whole structure. As in this approach whole structure is divided in to finite elements, it is known as “Finite element analysis”. FEA can be used to determine portion of an object which are more massive than the required, therefore mass can be reduced/add in amount of material.

The methods adopted by researchers previously, were model analysis and mathematical modeling of structures. But FEA is more reliable, quick and efficient technique now days followed. Again it becomes easier as sufficiently large computers are available to solve element equations. Present work on analysis of a Turning Center is done using simulation package of Creo 1.0. For the investigation on turning centre, rigorous analysis pertaining to Bed, Saddle and Head will be carried out with the FEA software. Following parameters will be considered according to shop floor data for FEA.

(a) Depth of cut will be taken 0.3, 0.6 ,0.9,1.2 mm

(b) Feed will be taken 0.1,0.14,0.15,0.2,0.3 mm/rev

(c) Cutting Speed will be taken 220,250 m/min

(d) Tool nose radius 0.4mm,0.8mm

(e) Materials will be AISI 1040 steel, AISI 410 steel, Mild steel and Aluminium

2.3.2 Investigation on cutting parameters for turning operations

2.3.2.1 Regression Analysis

To establish the prediction model, regression analysis is conducted with MINITAB using the experimental data. To develop surface roughness model, the experiments examined the impact of the following parameters on the surface roughness in finish turning.

1. Workpiece hardness.
2. Feed.
3. Tool nose radius
4. Depth of cut.
5. Cutting speed
6. Cutting time.

Regression analysis is considered to be one of the most important and most popularly used data mining techniques. Therefore, 2^{5-1} fractional design is selected. This resolution V design leads to 16 runs of the experiments. Two set of materials are used for this test with different hardness and chemical composition given in Table 2.12 and 2.13.

Table 2.12 Factors and levels for AISI 1040 steel and Aluminium

Level	Hardness (A)	Feed (B)	Tool radius (C)	Cutting Velocity(D)	Depth of Cut (E)
-1	AISI 1040 steel	0.06mm/rev	0.4 mm	220 m/min	0.3 mm
1	Aluminium	0.14mm/rev	0.8 mm	280 m/min	0.9 mm

Table 2.13 Factors and levels for AISI 410 steel and Aluminium

Level	Hardness (A)	Feed (B)	Tool radius (C)	Cutting Velocity	Depth of Cut (E)
-1	AISI 410 steel	0.06mm/rev	0.4 mm	220 m/min	0.3 mm
1	Aluminium	0.14mm/rev	0.8mm	280 m/min	0.9 mm

2.3.2.2 Optimization of cutting parameters by RSM

In presents research work author has used 3^4 full factorial design with RSM for the optimization of the cutting parameters with different materials like AISI 1040, AISI 410, Mild steel and Aluminium. Different levels of the cutting parameters are taken according to shop floor, given below.

1. Cutting speed (v) 220, 250, 280 m/min
2. Feed (f) 0.1, 0.15, 0.2 mm/rev
3. Depth of cut (d) 0.3, 0.6, 0.9 mm
4. Tool nose radius (r) 0.4, 0.8, 1.2 mm

The aim of the present study was, therefore, to develop the surface roughness prediction model of different materials like AISI 1040 steel, AISI 410 steel, Mild steel and Aluminium with the aid of statistical method and response surface optimization under various cutting conditions. By using response surface methodology and (3^4) full factorial design of experiment, quadratic model has been developed with 95% confidence level. Design of machine tool structure and analysis is discussed in next chapter.