MODELLING OF HARD TURNING PROCESS

A thesis submitted in partial fulfilment

Of the requirement for the degree of

Master of Technology

In
Mechanical Engineering

By

Suranjan Mohanty

Department of Mechanical Engineering
National Institute of Technology
Rourkela
May 2014

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CERTIFICATE

This is to certify that thesis entitled, **“Modelling of hard turning process’’** submitted by Suranjan Mohanty in partial fulfilment of the requirements for the award of Master of Technology in Mechanical Engineering with specialization “Production Engineering” during session 2012-2014 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by him under my supervision and guidance. To the best of our knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for award of any Degree or Diploma

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Abstract

In the present work, the workpiece material taken is chrome-moly alloy steel. This is a hard material having hardness 48 HRC. This alloy steel bears high temperature and high pressure and its tensile strength is high. It is very resistive to corrosion and temperature. For these useful properties it is used in power generation industry and petrochemical industry. Also it is used to make pressure vessels. For machining of workpiece the insert chosen is Tic coated carbide insert. Three factors speed, feed and depth of cut were taken at three levels low, medium and high. By the L_{27} orthogonal design twenty seven runs of experiments were performed. For each run of experiment the time of cut was 2 minutes. The output responses measured were surface roughness, power consumption, chip reduction co-efficient and tool wear (flank wear). All the output responses were analyzed by SN ratio, analysis of variance, and response table. The criteria chosen here is smaller the better and the method applied is Taguchi method.

CHAPTER-1

INTRODUCTION

Hard machining means machining of parts whose hardness is more than 45HRC but actual hard machining process involves hardness of 58HRC to 68HRC.The work piece materials used in hard machining are hardened alloy steel , tool steels , case – hardened steels , nitride irons , hard – chrome – coated steels and heat – treated powder metallurgical parts[16].

1.1.Advantages (Benefits) of hard machining:-

1. Complex part contours can be easily machined by this process.

2. Component types can be quickly changed over in this process.

3. In one set – up, many operations can be completed.

4. Metal removal rate is very high.

5. The CNC Lathe which is used for soft turning process can be used for this process.

6. Investment in machine tool is very low.

7. Metal chips produced in the process are environmentally friendly.

8. No coolant is required in many cases.

9. Tool inventory required is small.

1.2.Limitations (Draw backs) of hard machining:-

1. The cost of tooling in case of hard machining is higher than grinding.

2. For hard turning the length to diameter (L/D) ratio should be small. For unsupported work pieces it should not be more than 4:1 because long thin parts will induce chatter due to high cutting pressure.

3. For hard machining to be successful, the machine used must be rigid. The degree of hard turning accuracy is known from degree of machine rigidity. If we want to maximise the machine rigidity than we have to minimise overhangs, tool extensions and to eliminate shims and spacers.

4. The main challenge in hard machining is whether or not to use coolants, in some cases where there are interrupted cuts such as gears dry machining is good. Due to shock produced by thermal effect the insert will feel exiting and entering cut and insert will break. In case of continuous cut due to high tool tip temperature softens the area which are machined previously and decreases the value of hardness due to which material is easily cut. But due to dry machining part thermal distortion, handling and in process gauging is difficult so if coolant will be used then water based coolants should be used[16].

5. Surface finish decreases with increase of tool wear in the range of tool life.

6. In hard machining, a very thin layer of material which is harder than inner material is formed which is known as white layer. With tool wear increase its thickness increases. White layer is commonly formed on bearing steel and makes problem for bearing races which receive high contact stresses. The white layer causes bearing failure.

1.3. Features in which hard machining is different from conventional machining:-

1. When work material gets fractured chip in the form of saw tooth is formed. Within the range of shear strain crack is formed at the free surface of the workpiece.

2. Because of adiabatic shear segmental chips are formed in materials which are difficult to machine and its cross section is similar to saw-toothed chip formed in hard machining but these two chips are not same because they are produced due to different mechanisms.

3.The shear angle in case of hard machining is very small and increases with increase of hardness of work material and do not depend upon tool rake angle but the shear angle in case of traditional machining is large.

4. Radial (thrust) component of the cutting force is greater than tangential (power) component cutting force in case of hard machining. The difference between these two forces increases with increase of flank wear.

5. The tangential (power) component and radial (thrust) component depend upon the tool rake angle. At zero rake angle the components do not increase with hardness of material. At tool rake angle -20 degree, these components reduce with hardness of work material.

6. The chip compression ratio is equal to two in case of hard machining.

7. The radial component and tangential component depend upon flank wear differently. When flank wear increases from zero to 0.2mm the radial component increases four fold.

1.4.Factors distinguishing hard machining:-

To distinguish between hard machining conventional machining differences in energy balance should be analysed. The formula for balance of energy in metal cutting is given by $P_c = F_c.V = P_{pd} + P_{fr} + P_{jf} + P_{ch}$

Where F_c = power(tangential) component of the cutting force.

V = cutting speed

P_{pd} = power consumed due to plastic deformation

P_{fr} = power used on tool chip interface

P_{jf} = power used on tool work piece interface

P_{ch} = power used due to formation of new surfaces

The difference in the energy balance in conventional and hard machining of AISI steel 52100 the following conclusions are made[16].

1. In hard machining power spent on tool work piece surface is greatest but in conventional machining it is opposite.

2. Much power is spent in formation of new surfaces in hard machining.

3. Also power spent in the plastic deformation of layer being removed is much.

1.5.Hard turning:-

Hard turning is a process which eliminates the requirements of grinding operation. A proper hard turning process gives surface finish R_a 0.4 to 0.8 micrometre, roundness about 2-5 micrometre and diameter tolerance +/-3-7micrometre. Hard turning can be performed by that machine which soft turning is done. The starting point of hard turning is the material hardness 47 HRC but regularly hard turning is done on the material having hardness 60HRC and higher. The materials required for hard turning are tool steel, case-hardened steel, bearing steel, Inconel, Hastealloy, stellite and other exotic materials are also falling in the category of hard turning. The length to diameter ratio(L/D) ratio for unsupported work piece should not be more than 4:1 because though tailstock support is there for long thin parts chatter would be induced due to high cutting pressure. The degree of hard turning accuracy is measured by degree of machine rigidity. The system rigidity is more required for hard turning than machine rigidity. If rigidity of system is to be maximised then overhangs, extensions of tools, extensions of parts should be minimised and shims and spacers should eliminated. The purpose is to keep everything as close to turret or spindle as possible. The main challenge in hard turningis whether coolant will be used or not. In maximum cases hard turning will be performed dry. When hard turning will be performed without coolant, part will be hot. Due to this, it will be difficult for process gauging. To cool down the machined part coolant is used through the tool with high pressure. Additional problems are created due to flying cherry red chips. Mainly water-based and low concentration coolants are used in hard turning. In hard turning maximum heat is transferred to chip so if chip will be examined during and after cut then whether the process is well turned or not will be known. The chips should be glowing orange and flow like ribbon during continuous cut. If we will crunch the cooled chip and it will disintegrate then it shows that proper amount of heat is produced[16].

CHAPTER-2

LITERATURE REVIEW

Dilbag singh and P. Venkateswara Rao [1] investigated how surface roughness in bearing steel(AISI 52100) is effected by cutting condition and tool geometry. In this investigation mixed ceramic inserts which are made from Aluminium oxide and Titanium carbonitride(SNGA) which have different nose radius and different effective rake angle are used. In this study they concluded that S.R is effected by feed significantly followed by nose radius and cutting velocity. S.R. is effected very less by effective rake angle but interaction effect of nose radius and effective rake angle is significant. RSM is used to develop mathematical model.

Tugrul O zel et all [2] have investigated how surface roughness and resultant force in hard turning of AISI H13 steel is effected by cutting edge geometry, hardness of workpiece, feed and cutting speed. In this investigation four factor two level fractional factorial experiments are used and ANOVA is applied. Hardness of workpiece, geometry of edge, feed and cutting speed are the four factors. In hard turning experiment cutting force, feed force, thurst force and surface roughness were measured. From the study the significant factors on surface roughness are found to be hardness of workpiece, geometry of cutting edge, feed and cutting speed. Lower workpiece hardness and honed edge geometry produce better S.R. Geometry of cutting edge, hardness of workpiece, cutting speed affect force components.

B. Fnides et all conducted the experiment to determine the statistical model of surface roughness in hard turning of high alloyed steel X38CrMo5-1. This steel is hardened to 50HRC and is machined by mixed ceramic tool (insert cc650 of chemical composition 70% Al_2O_3 + 30% Tic) free from Tungsten on Cr-Mo-V basis, intensive to temperature changes and high wear resistance. By 3^3 full factorial design total 27 experiments were carried out. The levels low, medium, and high of the parameters are set. Mathematical models are deduced by multiple regression method in order to express the influence of each cutting regime element on surface roughness. Finally the result concludes that feed rate is the main factor influencing surface roughness followed by cutting speed. Depth of cut has not any important effect on surface roughness.

Dr. G. Hrinath Gowd et all [4] studied on F_x, F_y, F_z and S.R. and developed second order polynomial model for them. Mainly the problems in turning are due to cutting parameters (F_x, F_y, F_z and S.R.). Experiments were performed and it is concluded that cutting force, feed force , thurst force and surface roughnessare significantly affected by speed, feed and depth of cut. Prediction of mathematical models fo estimation of F_x, F_y, F_z and S.R , RSM is used.

K. Adarsh kumar et all [5] investigated how surface finish of EN-8 is affected by spindle speed, feed, depth of cut. Experimental measurements were determined multiple regression analysis and ANOVA. Cemented carbide inserts are used to predict surface roughness by multiple regression analysis. The purpose is to form arelation between cutting speed, feed and depth of cut to optimise S.R. using multiple regression analysis.

S.B. Salvi et all [6] studied on hard turning of 20MnCr5 steel. The purpose of this study is to analyse optimum cutting conditions to get lowest surface roughness in turning of 20MnCr5 steel. Taguchi method is applied in this process. Orthogonal array, signal to noise ratio and analysis of variance are applied to investigate the cutting characteristics. From the experiment it is concluded that feed rate has the significant role to produce lower surface roughness followed by cutting speed. In this experiment the cutting insert used is ceramic based TNGA160404.

F.Puh et all [7] used Taguchi design and optimised the process parameters for hard turning of AISI 4142 and in this experiment he used PCBN tool. L_9 orthogonal array having three level and four factor, SN ratio and ANOVA are used for this to study cutting parameters(speed, feed, depth of cut) with consideration of S.R. Multiple regression analysis was used to find first order linear and second order prediction model for surface roughness and independent variables.

Ali Riza Motorcu [8] investigated how S.R. in turning of AISI 8660 is affected by cutting speed, feed, depth of cut and tool nose radius using P.V.D. coated ceramic cutting tool. He analysed the process by orthogonal design, SN ratio, ANOVA and found that feed rate is the effective parameter followed by depth of cut and nose radius. Cutting speed is not significant. Due to surface hardening effect the interaction of feed and d.o.c was found to be significant.

R. Ramanujan et all [9] presented a new methodology for the optimisation of the machining parameters on turning Al-15% SiC_p metal matrix composites. Desirability function analysis is applied optimise the machining parameters. Experimental design for the experiment is L_{27}. Multiple performance considerations namely surface roughness and power consumption is applied for optimisation of the machining parameters such as cutting speed, feed rate, depth of cut. Composite desirability value is used to find optimum machining parameters.

A.D. bagawade et all [10] evaluated the area ratio of chip. He also evaluated S.R. in hard turning of AISI52100(EN-31) steel. The hardness of steel was about 48-50 HRC and this was machined by PCBN tool. The effect of speed, feed, depth of cut on chip area ratio and S.R were found.

S. Delijaicov et all [11] studied the effect of vibrations of cutting in hard turning process of AISI 1045. The specimen is first tempered and then quenched upto 53 HRC. Piezoelectric dynamometer as well as acquision data system is used for measurement. Excellent correlation is obtained between model and results and this showed frequency amplitude increases reliability of model by 5%.

P.V.S Suresh et all [12] used RSM to study surface roughness prediction model for turning of mild steel. CNMG cutting tools are used for experiment. A second order mathematical model is developed for surface roughness using RSM.

B. Sidda reddy et all [13] developed surface roughness model for machining of aluminium alloys , using adaptive neuro-fuzzy interference system(ANFIS). CNC machine is used for experimentation with carbide cutting tool for machining Aluminium alloys for a wide range of machining conditions. The ANFIS model has been developed in terms of machining parameters to predict the surface roughness using train data. To validate the model the experimental validation runs were conducted. Percentage deviation and average percentage deviation has been used to judge accuracy and ability of model. Same data were modelled by RSM and the ANFIS results are compared with RSM results and it is concluded that ANFIS are superior to RSM results.

Tugrul o Zel, Yigit Karpat [14] used neural network modelling for prediction of surface roughness and tool flank wear over machining time for varity of cutting conditions in finish hard turning. For training neural network model the data from measured surface roughness and tool flank wear of AISI H-13 steel were used. For other cutting conditions trained neural network models were used in predicting surface roughness and tool flank wear. Comparison between neural network model and regression model is done and better prediction is obtained from predictive neural network model for surface roughness and tool wear within the training range. When feed rate is decreased surface roughness becomes better but tool wear becomes faster. When cutting speed is increased tool wear is increased but surface roughness becomes better. When work piece hardness is increased surface roughness becomes better but tool wear becomes larger. Finally it is concluded that CBN inserts with honed edge geometry performed better surface roughness and tool wear development.

Y.Kevin Chou, Hui Song [15] employed a mechanistic model to estimate the chip formation forces. Assuming linear growth of plastic zone on the wear land and quadratic decay of stresses in the wear land forces are modelled. Increasing feed rate and cutting speed adversely affect maximum machined surface temperature in new cutting tool but increasing depth of cut favourably affect the maximum machined surface temperature.

CHAPTER-3

THEORITICAL STUDY

3.1 Surface roughness:-

Due to the increased knowledge and constant improvement of the surface textures gives the present machine age a great advancement. Due to the demand of greater strength and bearing loads smoother and harder surfaces are needed. The surface texture has direct contact with the functioning of machine parts, load carrying capacity, tool life, fatigue life, bearing corrosion and wear qualities. Failure due to fatigue always occurs at the sharp corners because of stress concentration at that place. Sharp corner is the place where any surface irregularity starts and that part fails earlier. Surface irregularity at non-working surface also matters for failure. Different requirements demand different types of surfaces so measurement of surface texture quantitatively is essential. The imperfections on the surface are in the form of succession of hills and valleys varying both in height and spacing. Any material being machined by chip removal process cannot be finished perfectly due to some departures from ideal conditions. Due to conditions not being ideal the surface being produced will have some irregularities and these irregularities can be classified into four categories given as follows[17]:-

a) First order:- This type of irregularities are arising due to inaccuracies in the machine tool itself for example lack of straightness of guide ways on which tool post is moving. Irregularities produced due to deformation of work under the action of cutting forces and the weight of the material are also included in this category.

b) Second order:- This order of irregularities are caused due to vibration of any kind such as chatter marks.

c) Third order:- If the machine is perfect and completely free of vibrations still some irregularities are caused by machining due to characteristics of the process. For example feed mark of cutting tool.

d) Fourth order:- This type of irregularities are arised due to rupture of the material during the separation of the chip.

Further these irregularities of four orders can be grouped under two groups. First group includes irregularities of considerable wave-length of the periodic character resulting from mechanical disturbances in the generating set up. These errors are termed as macro-geometrical errors and include irregularities of first and second order. These errors are also referred to as waviness or secondary texture. Second group includes irregularities of small wavelength caused by the direct action of the cutting element on the material or by some other disturbances such as friction, wear or corrosion. Errors in this group are referred to as roughness or waviness.

3.1.1Terms used in surface finish:-

Roughness:- This is produced due to irregular structures in the surface roughnesswhich is resulted from the inherent action of production process.

Waviness:- This is produced due to deflection in work piece or machine vibrations produced in machine.

Flaws:- The irregularities which are produced at one place or infrequently in widely varying intervals in a surface are called flaws.

Centre line:-The line about which roughness is measured.

Traversing length: - It is the length of the profile necessary for the evaluation of the surface roughness parameters. The traversing length includes one or more sampling lengths.

Sampling length:-It is the length of profile necessary for the evaluation of the irregularities to be taken into account also known as cut off length.

Mean line of the profile:- It is the line having the form of the geometrical profile and dividing the effective profile so that within the sampling length the sum of squares of the distances between effective points and the mean line is minimum.

Centre line of the profile:-It is the line parallel to the general direction of the profile for which the areas embraced by the profile above and below the line are equal.

Spacing of the irregularities:- It is the mean distance between the more prominent irregularties of the effective profile, within the sampling length.

3.1.2 Different parameters used in measuring surface roughness:-

Arithmetic average roughness:- $R_a = 1/L\int_0^L mod(h)dx$ over 2-20 consecutive sampling lengths.

Average peak-to-valley height(R_z):-This is the average of single peak-to-valley heights from five adjoining sampling lengths.

Depth of surface smoothness:-$R_p = 1/L\int_0^L (Hmax - H)dx$

Levelling depth(R_u):- Distance between mean line and a parallel line through highest peak.

Mean depth(R_m):-Distance between mean line and a parallel line through the deepest valley.

Maximum peak-to-valley height(R_{max}):-Largest single peak-to-valley heights in five adjoining sampling lengths.

Root mean square roughness:-$R_q = \sqrt{1/L\int_0^L h^2\, dx}$

3.1.3Methods of measuring surface roughness:-

There are two methods of measuring the finish of machined part[17]. They are :-

- (i) Surface inspection by comparison methods
- (ii) Direct instrument measurements

(i) Surface inspection by comparison:-

In comparative methods the surface texture is assessed by observation of the surface. But these methods are not reliable as they can be misleading if comparison is not made with surfaces produced by same techniques. The various methods available under comparison method are:-

- (i) Torch inspection
- (ii) Visual inspection
- (iii) Scratch inspection
- (iv) Microscopic inspection
- (v) Surface photographs
- (vi) Micro-Interferometer
- (vii) Wallace surface dynamometer
- (viii) Reflected light intensity

(ii)Direct instrument measurement:-.

Stylus probe instruments are as follows:- Surface finish of any surface can be measured by this method. In this type measurement electrical principles are used and they are stylus probe type instrument. There are two types of these electrical instruments. Carrier modulating principle is the first type of operation. The movement of the stylus exploring the surface are caused to high frequency carrier current. Second type works onvoltage generating principle.

- (i) Profilometer

(ii) The Tomlinson surface meter
(iii) The Taylor-Hobson Talysurf
(iv) Stylus

Out of the above four only Taylor-Hobson Talysurf is used in our experiment this to calculate surface roughness.

3.2.Tool wear in turning:-

A constant cutting force is acting in turning operation and turning is a continuous process. A high temperature is produced at the tool/chip interface because of constant heat derived from shear deformation energy and friction. The principal wear factor in turning is high temperature at the tool rake face. The temperature is around 600 degree for austenitic steels, super alloys or titanium alloys. Tool wear mechanisms in turning are basically four types in turning[16]. They are as follows:-

(i) Crater wear
(ii) Notch wear
(iii) Flank wear
(iv) Adhesion

- Crater wear: It is a chemical or metallurgical wear. Crater wear is produced because small particles of the tool rake surface diffuse or adhere on fresh chip. Scar like shape is produced on the rake face due to mechanical friction and it is parallel to the major cutting edge. In turning of titanium alloys and low thermal conductivity materials crater wear is produced.

  - Notch wear: It is a combination of flank wear and rake face wear which occurs just in the point where major cutting edge intersects the work surface. This type of wear is produced in those materials which have a tendency to surface hardening due to mechanical loads. When tool passes rub the fresh machined surface increases hardness of the outer layer. In turning of austenitic stainless steels and nickel-based alloys notch wear is produced.

- Flank wear: This type of wear is produced on the flank face of the tool. Wear land formation is not uniform along major and minor cutting edge of the tool. This type of wear is produced in case of hard materials because there is not any chemical affinity between tool and material. The wear mechanism is due to abrasion in this case.

  - Adhesion: Welding occurs between the fresh surface of the chip and tool rake face because high pressure and temperature. If materials have metallurgical affinity the there will be better welding and that will produce a thick adhesion layer and tearing of the softer rubbing surface at high wear rate. In Aluminium alloys this type of wear is produced in dry conditions. In hard machining this type of wear is not produced.

Wear curve: The following curve shows mean flank wear(VB) along time for various cutting speeds. This wear curve is divided into three regions as given below in fig-3.5.

  - Initial wear region: In this region the sharp new edge worn rapidly. The wear size VB = 0.05-0.1 mm in this region.
  - Steady wear region: In this region wear rate is constant and increases slowly. In this zone VB=0.05-0.6 mm onwords.

- Severe wear region: In this region tool wears in very high rate. When this zone is reached anew tool must be used in place of worn tool or sharpening must be done before tool breakage.

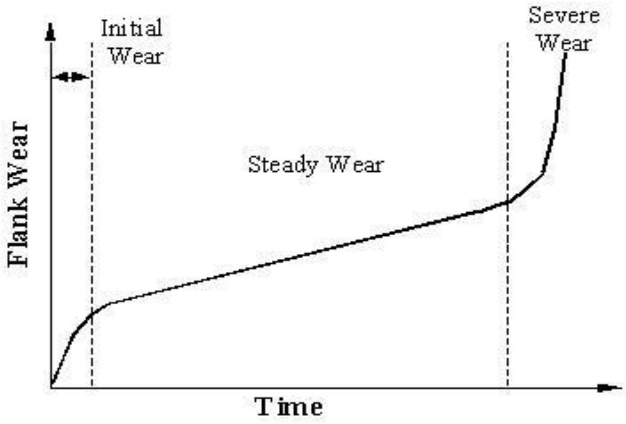


Fig-3.1: Development of flank wear with respect to time

3.3 Cutting tool materials used in case of hard machining:-

During hard machining high temperatures are produced and big mechanical load is there due to speed so cutting tools must withstand these two things. In some cases the temperature in the tool/chip interface reaches around 700 degree centigrade[16]. Severe friction is produced between tool and chip as well as tool and new machined surface. Keeping in mind the above things the cutting tool materials should have the following properties:

- Cutting tool substrate material must be chemically and physically stable at high temperatures.
- Material hardness must withstand high temperatures produced at the chip/tool interface.
- For abrasion and adhesion mechanisms tool material should have a low wear ratio.

- To perform interrupted and intermittent cutting tool material must have enough toughness to avoid fracture.

Starting from the lowest hardness to the highest hardness the tool materials can be classified as follows:-

- High speed steel (H.S.S.)
- Sintered carbide
- Ceramics
- Extra hard materials

High speed steel: These are of high content carbon steels with a high proportion of alloying elements such as tungsten, molybdenum, chromium, vanadium and cobalt. Hardness is about 75 HRC. The T series includes tungsten, the M series molybdenum. Vanadium produces the hardest carbides and produces super high speed steels. HSS can withstand temperature upto 500 degree centigrade. The HSS produced by power metallurgy process(HSS-PM) possesses a higher content alloying elements and unique properties like higher toughness, higher wear resistance, higher hardness, higher hot hardness.

Sintered carbide: Mixing tungsten carbide micro grains with cobalt at high temperature and pressure sintered carbide tools are produced. These are also known as cemented carbide tools. Tantalum, Titanium, Vanadium carbides are also mixed in small amount. Sintered carbides are described by two main factors. One is the ratio of tungsten carbide and cobalt. Cobalt ranges from 6 to 12% and it acts as binder. Melting point of Cobalt is 1493 degree centigrade. Cobalt forms a soluble phase with tungsten carbide grains at 1275 degree centigrade and helps to reduce porosity. Second is the micro grain size. Micro grain size is smaller than 1 micrometre and submicrograin are smaller than half micron. The hardness of sintered carbide increases with the reduction in binder content and tungsten carbide grain size. Hardness of sintered carbide ranges from 600HV to 1200HV. Sintered carbides are manufactured in two forms, integral tools and inserts. Sintered carbides are classified into six groups M, P, K, N, S, H. Each scale includes a numerical scale for it. In USA C-x scale is used. M, grade includes the sintered carbides suitable for stainless steel machining. P, includes sintered carbides for low and medium carbon steels and light alloyed steels. K, includes sintered carbides for cast irons and alloyed steels. N, is used for Aluminium alloys, S, for heat resistant alloys and H, for tempered and hardened steels. For each of the above grades the two digit number 01 to 40 is used, except P, for which 01 to 50 is used. Lower number indicates harder grades and higher number indicates tougher grades. In USA C-1 to C-4 are general grades for cast iron, C-5 to C-8 are for steel alloys, C-9 to C-11 for high wear applications, C-12 to C-14 for impact cases. The two basic groups of carbides used for machining are tungsten carbide and Titanium carbide[16].

a) Tungsten carbide: WC particles are bonded together with cobalt matrix to give tungsten carbide composite. By powder metallurgy technique WC particles are bonded together with cobalt in a mixer resulting in cobalt matrix surrounding WC particles and by this process tungsten carbide tools are manufactured. WC is frequently compounded with Titanium and Niobium to impart special properties to the carbide. Steels, Cast irons and abrasive non-ferrous materials are cut by Tungsten carbide tools.
b) Titanium carbide: Tic has higher wear resistance than WC but it is not as tough as WC. Nickel-molybdenum alloy is used as matrix. Steels and cast irons can be machined by TIC.

Ceramics: Ceramics can be used for machining the metals at high cutting speeds and in dry machining conditions because these are very hard and refractory materials which can withstand up to 1500 degree centigrade without chemical decomposition. Ceramic powders are used to mould ceramic materials at pressures 25MPa. Sintering of ceramic materials are done at 1700 degree centigrade. Ceramic tools may be of three types for example alumina tools (Al_2O_3), Silicon nitride (Si_3N_4) and sialon which is combination of Si, Al, O and N. Alumina tools contain mixture of titanium, magnesium, chromium, or zirconium oxides distributed into alumna matrix homogenously. Due to this toughness gets improved. Silicon nitride ceramics have a higher resistance to thermal shock and a higher toughness. Ceramics have a needle like structure embedded in grain boundary which increases fracture toughness. These are applied for roughing cast iron under heavily interrupted cuts. Ceramic tools must be kept hot throughout the operation and shocks on tool edges at tool entrances exits from the work piece must be avoided.

Extra-hard materials: Extra-hard materials include PCD and PCBN. PCD is used for machining abrasive non-ferrous metals, plastics and composites. PCBN is used for machining of hardened tool steels and cast irons.

3.4.Taguchi method:-

The methodology applied in this study is Taguchi method. It is a combination of methodologies by which inherent variability of materials and manufacturing processes has been taken into consideration during design. Controlled and noise both factors are considered in this design. Taguchi design is similar to design of experiment but it conducts the orthogonal experimental combinations which makes the method more effective than fractional factorial design. Taguchi method uses special design of orthogonal arrays to study the entire patameter space with small no of experiments. Taguchi uses the loss function for the measurement of the performance characteristics deviating from the desired value. The value of loss function is converted to S/N ratio. There are three types of S/N ratios e.g lower-the-better, Higher-the-better, Nominal-is-best. The formula for three types of S/N ratio is given below.

Nominal-is-the-best:S/N$_T$=10log($\frac{\bar{y}}{s_y^2}$)

Larger-is-the-better (maximise):S/N$_L$=-10log($\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$)

Smaller-is-the-better (minimise):S/N$_s$=-10log($\frac{1}{n}\sum_{i=1}^{n}y_i^2$)

Where $\bar{y}$ is the average of observed data and s_y^2 is the variance

of y, n is the no. of observations and y is the observed data. S/N ratio is always expressed in decibel. If the objective is to reduce the variability around a specific target then S/N$_T$ is used. If the system is optimized when response is as large as possible S/N$_L$ is used. If the system is optimized when the response is optimized as small as possible S/N$_s$ is used. The goal of this research is to produce minimum surface roughness, minimum power consumption, minimum chip reduction co-efficient, and minimum tool wear in turning operation. The larger value of S/N ratio means the better performance characteristics so the optimal level of the process parameters is the level with the highest S/N ratio. A statistical analysis of variance is performed to see statistically significant process parameters.

In this paper three factors speed, feed and depth of cut are taken as the control parameters. Each factor has three levels low, medium and high so L27 orthogonal array has been choosen which has 27 rows corresponding to the number of parameter combinations having 26 degrees of freedom.

CHAPTER-4

EXPERIMENTAL DETAILS

4.1. Work piece material: The work piece is chrome-moly alloy which is prepared at cast profile private limited, Kalunga. Its length is 600 mm and diameter is 50 mm. It is heat treated to make its hardness upto 48 HRCThe photograph of work piece material and chemical composition of the CR-MO alloy is given below in fig-4.1:

Fig-4.1: Work piece material(Cr-Mo round bar)

Dimension of Cr-Mo alloy:

Length of bar = 600 mm

Diameter of bar = 50 mm

Hardness of material =48 HRC

Chemical composition of Cr-Mo alloy(Table-4.1)

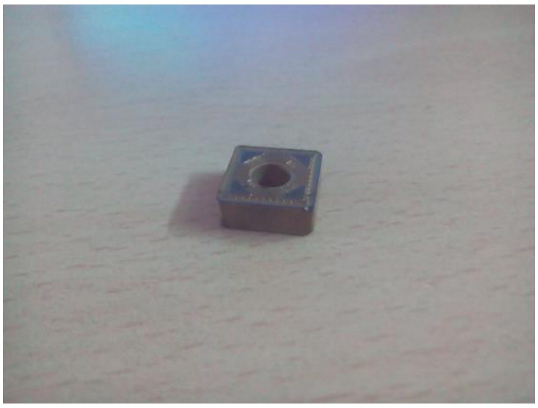
Carbon	Mn	Cr	Mo
0.15 max	0.3-0.6	4.0-6.0	0.44-0.65

4.2.Cutting inserts:-

Cutting inserts used in this experiment are four in number. Each insert has eight edges so for 27 experiment all eight edges of first three are used and three edges of last insert is used. The specification of insert is SNMG 120408. The inserts are Tic coated carbide inserts. The photographs of all inserts used in experiment, their specification and geometry are given below in fig4.2(a), (b), (c), (d):

Insert-1

[a]



Insert-2

[b]

Insert-3 Insert-4

[c] [d]

Fig-4.2

Specification of inserts:-

SNMG120408

S:-Insert shape (square)

N:-Clearance angle (0 degree)

M:-Tolerances

G:-Form of top surface

12 mm:-Cutting edge length

04 mm:-Insert thickness

08 mm:-Corner radius

Geometry of inserts:-

Inclination angle=-6 degree

Orthogonal rake angle=-6 degree

Orthogonal clearance angle= 6 degree

Auxiliary cutting edge angle= 15 degree

Principal cutting edge angle= 75 degree

Nose radius = 0.8 mm

4.3.Tool holder: - The tool holder used for the experiment is PSBNR2525M12. Its photograph and specification is given below in fig4.3.

Fig-4.3:Tool holder (PSBNR2525M12)

Specification of tool holder:-

P:-Clamping method (Retained via bore)

S:-Insert shape (square)

B:-Style (75 degree)

N:-Clearance angle (0 degree)

R:-Cutting direction (right handed)

25 mm:-Shank height

25 mm:-Shank width

M:-Tool length150 mm

12 mm:-Cutting edge length

4.4.Lathe machine used for experiment:-

The type of machine used for hard turning Cr-Mo alloy is conventional lathe machine with high rigidity. Cutting tests were carried out under dry cutting environment. Dry machining has been considered as the machining of the future due to concern regarding the safety of the environment. The experimental set-up is given in fig-4.4.

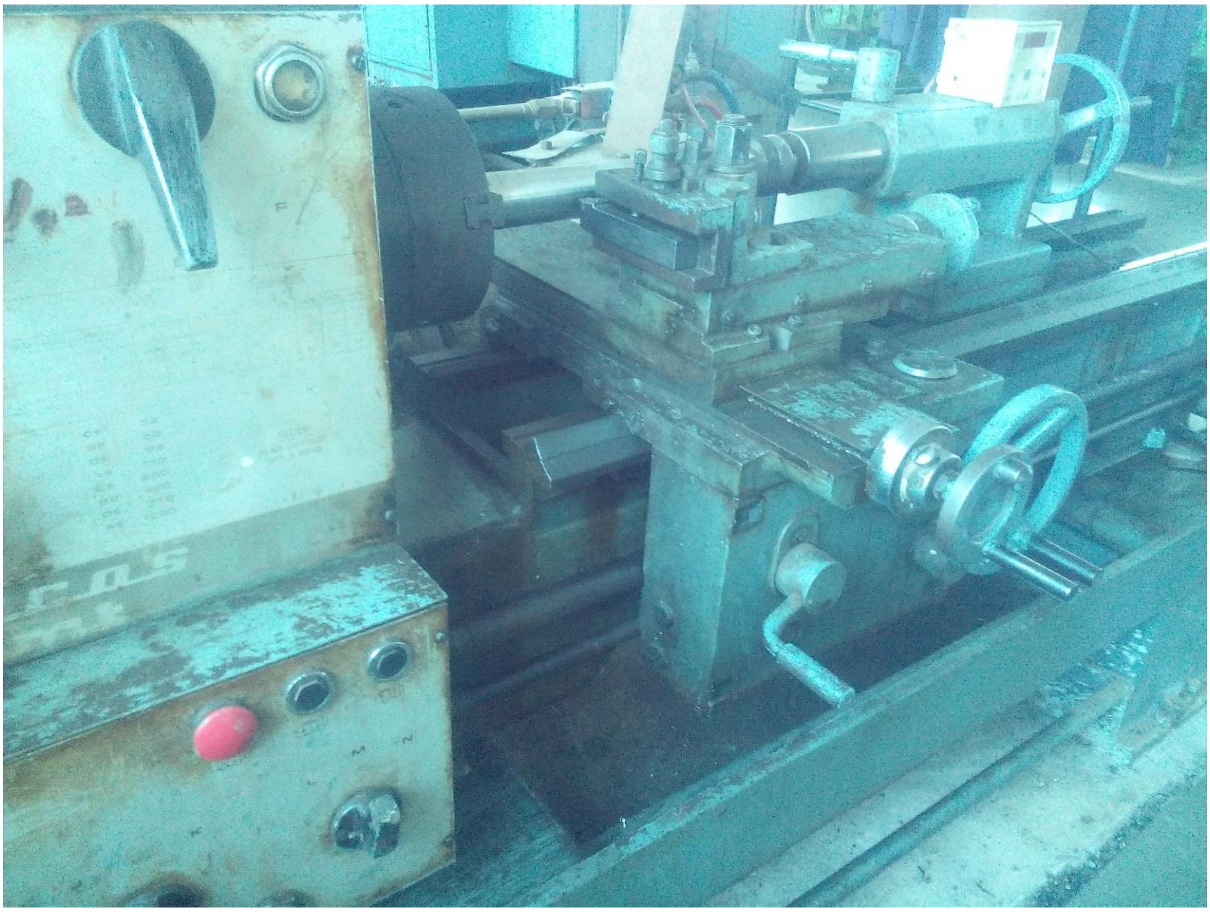


Fig-4.4:Lathe machine with work piece

4.5.Surface roughness tester used in experiment:-

Fig-4.5:Taylor-Hobson (sutronic 3+)

Specification:-

Traverse speed: 1 mm/second

Measurement unit: Metric/Inch

Cut-off values: 0.25 mm, 0.80 mm, 2.5 mm (0.01 in, 0.03 in, 0.1 in)

Parameters: R_a, R_q, R_z(DIN), R_y and S_m

Calculation time: Less than reversal time or 2 second whichever is longer

4.6.Micrometre used to calculate chip thickness:- The micrometre used to calculate chip thickness is given below in fig-4.6 with its specification.

Fig-4.6: Micrometre

Specification:

Least count: 0.01 mm

Range: 0-25 mm

4.7.Experimental procedure:

The rough work piece of chrome-moly alloy bought from cast profile Ltd, kalunga is first turned to clear the rough skin using uncoated carbide insert. The final diameter of the work piece is made 50 mm. The two ends of the work piece are faced and centring is done using carbide centre drill. The final length of the work piece was made 600 mm. The purpose of this experiment is to find the effect of speed, feed and depth of cut on output responses like surface roughness, power consumption, chip reduction coefficient and tool wear. The levels of speed, feed and depth of cut are three each which is given in table-4.2. Total 27 experiments were done according to L_{27} orthogonal array. The work piece was held rigidly on the lathe and for each set of the data work piece is turned for 2 minutes so 27 cuts were made on the workpiece which is shown in Fig-4.1. The surface roughness component (R_a) was measured using Taylor/Hobson (sutronic 3+) for 27 cuts. The power consumed in machining was measured by wattmeter connected to the Lathe machine. The wattmeter gave the reading of voltage (V), current (I) and power factor (cosϕ) for each of the runs of the experiment. The power consumption can be given by formula P= V.I.cosϕ. The four inserts used for the experiment are shown in Fig-4.2(a),4.2(b), 4.2(c), 4.2(d). Each insert has eight edges so all eight edges of first three inserts and three edges of last one were used for 27 experimental runs. The chips were collected for 27 experiments and their thickness were calculated using micrometer shown in Fig-4.6. The chip reduction co-efficient can be given by formula below.

Chip reduction co-efficient = $\frac{Chip\ thickness}{Undeformed\ chip\ thickness}$

Undeformed chip thickness = f $\sin K_r$ where f is the feed and k_r is the principal cutting edge. The table for power and chip reduction co-efficient were shown in table-4.3.

Table-4.2

Levels	Speed in rpm	Feed in mm/rev	D.O.C in mm
Low	250	0.1	0.3
Medium	420	0.13	0.5
High	710	0.15	1.0

Table-4.3

Run.no	Speed In r.p.m	Feed In mm/rev	d.o.c in mm	V In volt	I in amp	P.F.	P=$\frac{V.I.(P.F)}{1000}$ in k.w.	C.T. In Mm	ξ=C.T/U.C.T
1	250	0.1	0.3	410	4.7	0.21	0.405	0.11	1.138
2	250	0.1	0.5	409.3	4.81	0.31	0.610	0.20	2.070
3	250	0.1	1.0	400.8	4.42	0.28	0.496	0.29	3.002
4	250	0.13	0.3	411.4	4.72	0.20	0.388	0.08	0.637
5	250	0.13	0.5	406.6	4.69	0.25	0.476	0.17	1.353
6	250	0.13	1.0	401.5	4.53	0.30	0.545	0.13	1.035
7	250	0.15	0.3	416	4.98	0.21	0.435	0.14	0.966
8	250	0.15	0.5	407.6	4.72	0.25	0.480	0.27	1.863
9	250	0.15	1.0	410.2	4.81	0.30	0.592	0.31	2.139
10	420	0.1	0.3	415.6	4.81	0.25	0.500	0.14	1.449
11	420	0.1	0.5	408.6	4.70	0.27	0.518	0.14	1.449
12	420	0.1	1.0	400.8	4.70	0.42	0.791	0.22	2.277

13	420	0.13	0.3	415.7	4.92	0.24	0.491	0.07	0.577
14	420	0.13	0.5	407.6	4.67	0.27	0.514	0.16	1.274
15	420	0.13	1.0	403.1	4.78	0.43	0.830	0.26	2.070
16	420	0.15	0.3	418.5	4.87	0.24	0.489	0.08	0.552
17	420	0.15	0.5	408.6	4.78	0.32	0.624	0.20	1.380
18	420	0.15	1.0	402.6	4.75	0.43	0.822	0.21	1.449
19	710	0.1	0.3	417.0	5.06	0.31	0.654	0.09	0.724
20	710	0.1	0.5	407.8	4.92	0.38	0.762	0.04	0.414
21	710	0.1	1.0	401.5	5.01	0.58	1.166	0.11	1.138
22	710	0.13	0.3	416.0	4.94	0.32	0.662	0.05	0.398
23	710	0.13	0.5	410.6	4.98	0.40	0.818	0.12	0.955
24	710	0.13	1.0	400.2	5.45	0.61	1.330	0.19	1.513
25	710	0.15	0.3	412.3	4.96	0.41	0.838	0.15	1.035
26	710	0.15	0.5	407.8	4.78	0.39	0.760	0.09	0.621
27	710	0.15	1.0	402.3	5.02	0.49	0.989	0.22	1.518

In the above table P.F means power factor, C.T means chip thickness, U.C.T means undeformed chip thickness, ξ stands for chip reduction co-efficient. P stands for power.

4.8.Final experimental table:-

Final experimental table-4.4 is given below. This table contains three input variables speed, feed and depth of cut. The levels of were in r.p.m. and they were 250, 420 and 710 r.p.m. These speeds were converted into m/min using formula $\frac{\pi DN}{1000}$ where D is the diameter of work piece and N is the r.p.m. of Lathe machine. The outputs are surface roughness in micron, power in k.w. chip reduction co-efficient and tool wear in mm.

TABLE:-4.4

Run.no	Speed in m/min	Feed in mm/rev	d.o.c. in mm	S.R in micron	Power in k.w	Chip reduction co-efficient	Tool wear in mm
1	39.275	0.1	0.3	1.10	0.405	1.138	1.26
2	39.275	0.1	0.5	1.44	0.610	2.070	0.96
3	39.275	0.1	1.0	0.04	0.496	3.002	0.88
4	39.275	0.13	0.3	1.56	0.388	0.637	1.62
5	39.275	0.13	0.5	1.66	0.476	1.353	0.675
6	39.275	0.13	1.0	1.42	0.545	1.035	0.657
7	39.275	0.15	0.3	1.02	0.435	0.966	1.96
8	39.275	0.15	0.5	1.82	0.480	1.863	0.813
9	39.275	0.15	1.0	1.50	0.592	2.139	0.965
10	65.982	0.1	0.3	0.88	0.500	1.449	0.624
11	65.982	0.1	0.5	1.64	0.518	1.449	0.58
12	65.982	0.1	1.0	0.80	0.791	2.277	0.923
13	65.982	0.13	0.3	0.72	0.491	0.557	0.363
14	65.982	0.13	0.5	1.70	0.514	1.274	0.798
15	65.982	0.13	1.0	1.16	0.830	2.070	0.827
16	65.982	0.15	0.3	0.84	0.489	0.552	0.522
17	65.982	0.15	0.5	1.20	0.624	1.380	0.457

18	65.982	0.15	1.0	1.14	0.822	1.449	0.572
19	65.982	0.1	0.3	0.84	0.654	0.724	1.204
20	111.541	0.1	0.5	1.32	0.792	0.414	0.147
21	111.541	0.1	1.0	1.18	1.166	1.138	0.16
22	111.541	0.13	0.3	1.2	0.662	0.398	1.588
23	111.541	0.13	0.5	1.32	0.818	0.955	1.465
24	111.541	0.13	1.0	2.50	1.330	1.513	0.916
25	111.541	0.15	0.3	1.92	0.838	1.035	1.787
26	111.541	0.15	0.5	3.08	0.760	0.621	0.967
27	111.541	0.15	1.0	1.50	0.989	1.518	0.601

4.9.Chip collected during experiment:-

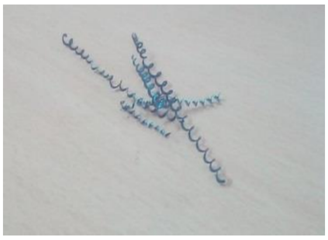
The chips were collected during all 27 experiments and their thickness were measured using micrometre shown in Fig-4.6. The chip reduction co-efficient was calculated for each chip using the formula Chip reduction co-efficient = $\frac{Chip\ thickness}{Undeformed\ chip\ thickness}$

Undeformed chip thickness = f sinK_r where f is the feed and k_r is the principal cutting edge of the insert. The photographs of all the chips were shown below in fig-4.7(i) upto (xxvii).

[i]

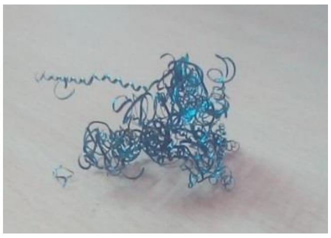
[ii]

[iii]



[iv]

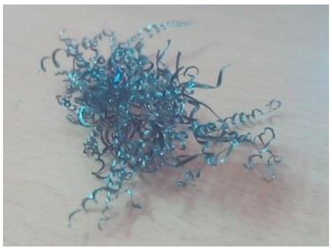
[v]



[vi]

[vii]

[viii]



[ix]

[x]

[xi]

[xii]

[xiii]

[xiv]

[xv]

[xvi]

[xvii]

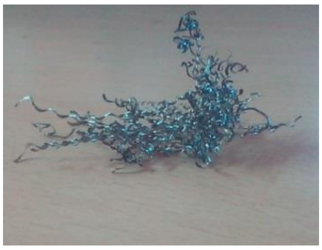
[xviii]

[xix]

[xx]

[xxi]

[xxii]



[xxiii]

[xiv]

[xxv]

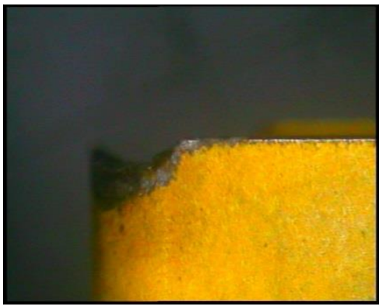
[xxvi]

[xxvii]

Fig-4.7

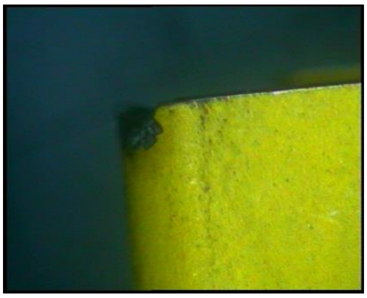
4.10.Photographs of tool wears:-

The photographs of 27 tool wears of edges of inserts taken by stereo zoom microscope are given in Fig-4.8(i) up to (xxvii).



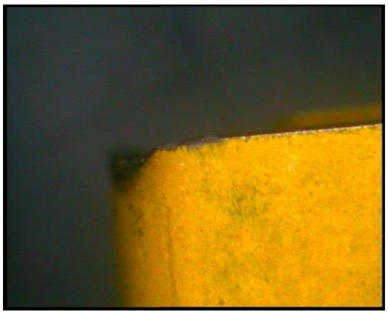
[i]

[ii]



[iii]

[iv]



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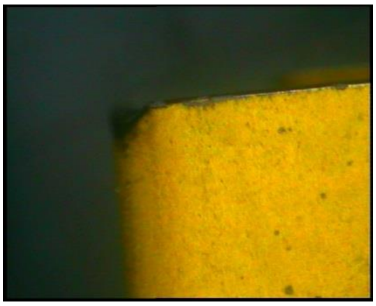

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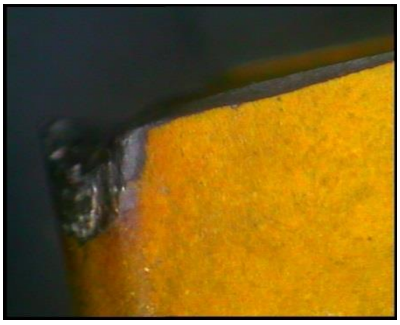
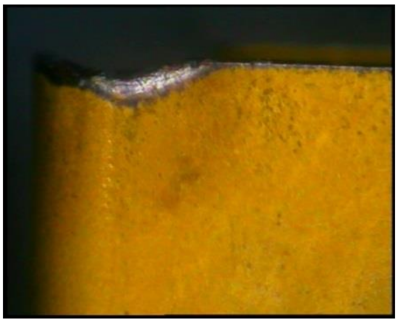


[vii]

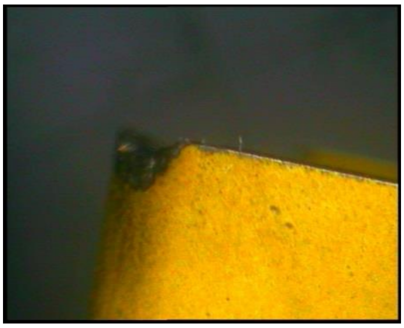
[viii]

[ix]



[x]

[xi]



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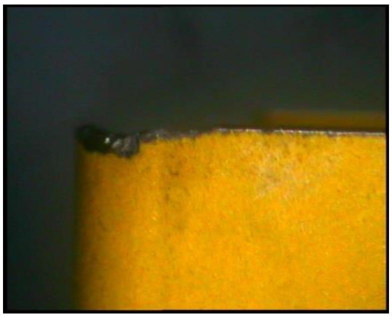

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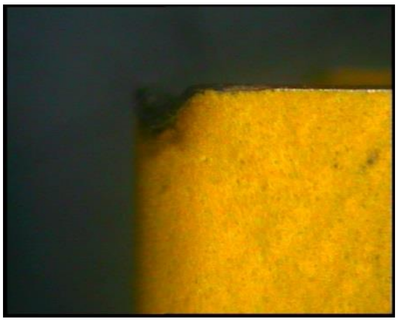
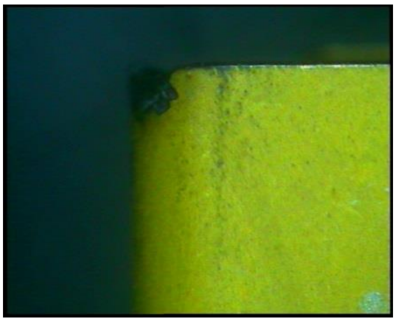


[xiv]



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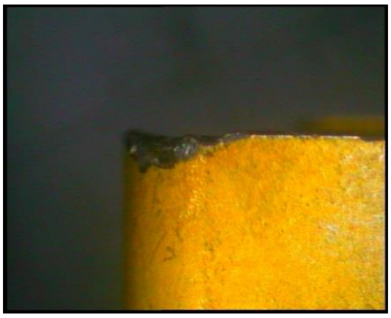

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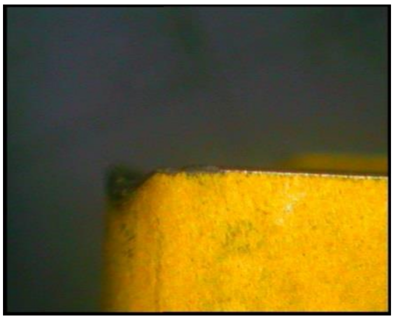
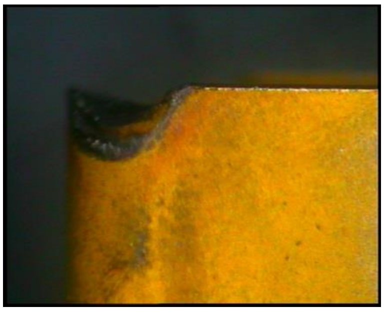
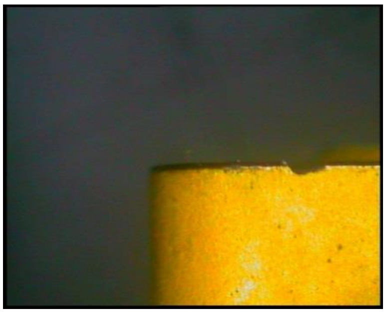


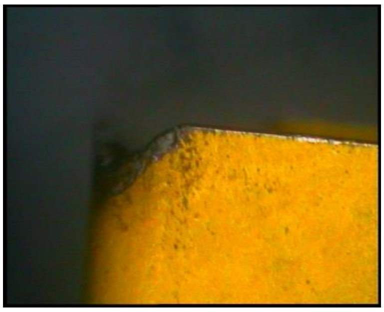
[xvii]

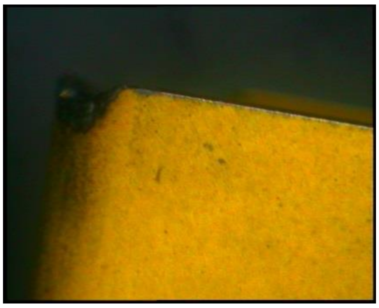
[xviii]



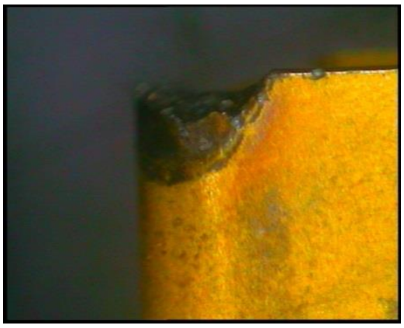


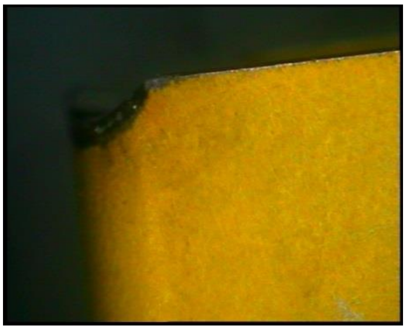
[xix] [xx] [xxi]

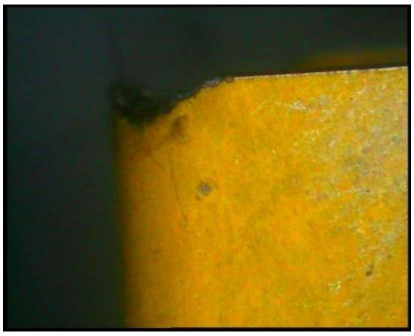




[xxii] [xxiii] [xiv]







[xv] [xvi] [xvii]

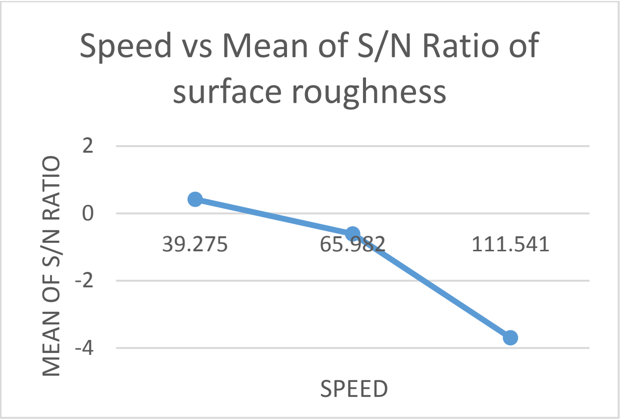
Fig-4.8

CHAPTER-5

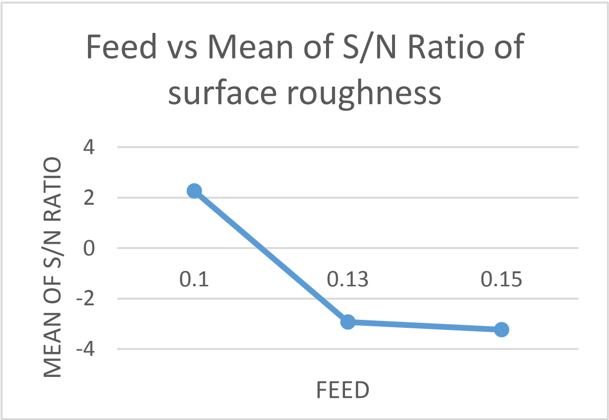
RESULTS AND DISCUSSION

5.1. Main effect plots for surface roughness:-

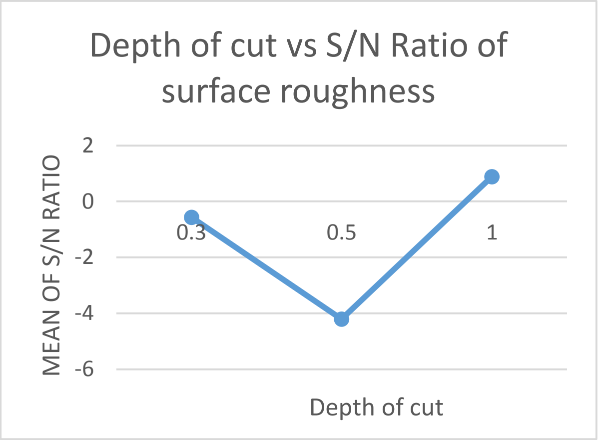
The Fig-5.1(a), (b), (c) shows the main effects for surface roughness that means the graphs of speed vs. mean of S/N ratios of surface roughness, feed vs. mean of S/N ratios of surface roughness, depth of cut vs. mean of S/N ratios of surface roughness for lower is better. As the speed increases the mean of S/N ratios decreases that means good surface finish is obtained with increase in speed. From the graph5.1(b) it is clear that as the feed increases surface roughness decreases that means increase in feed also gives good surface finish. From the graph 5.1(c) it is clear that as the depth of cut increases first surface roughness decreases upto some value and then increases. From three graphs the slope of feed vs. mean of S/N ratio graph is largest, depth of cut vs. mean of S/N ratio graph possesses second largest slope so surface roughness is significantly affected by feed and depth of cut but cutting speed has not significant effect on surface roughness.



[a]



[b]

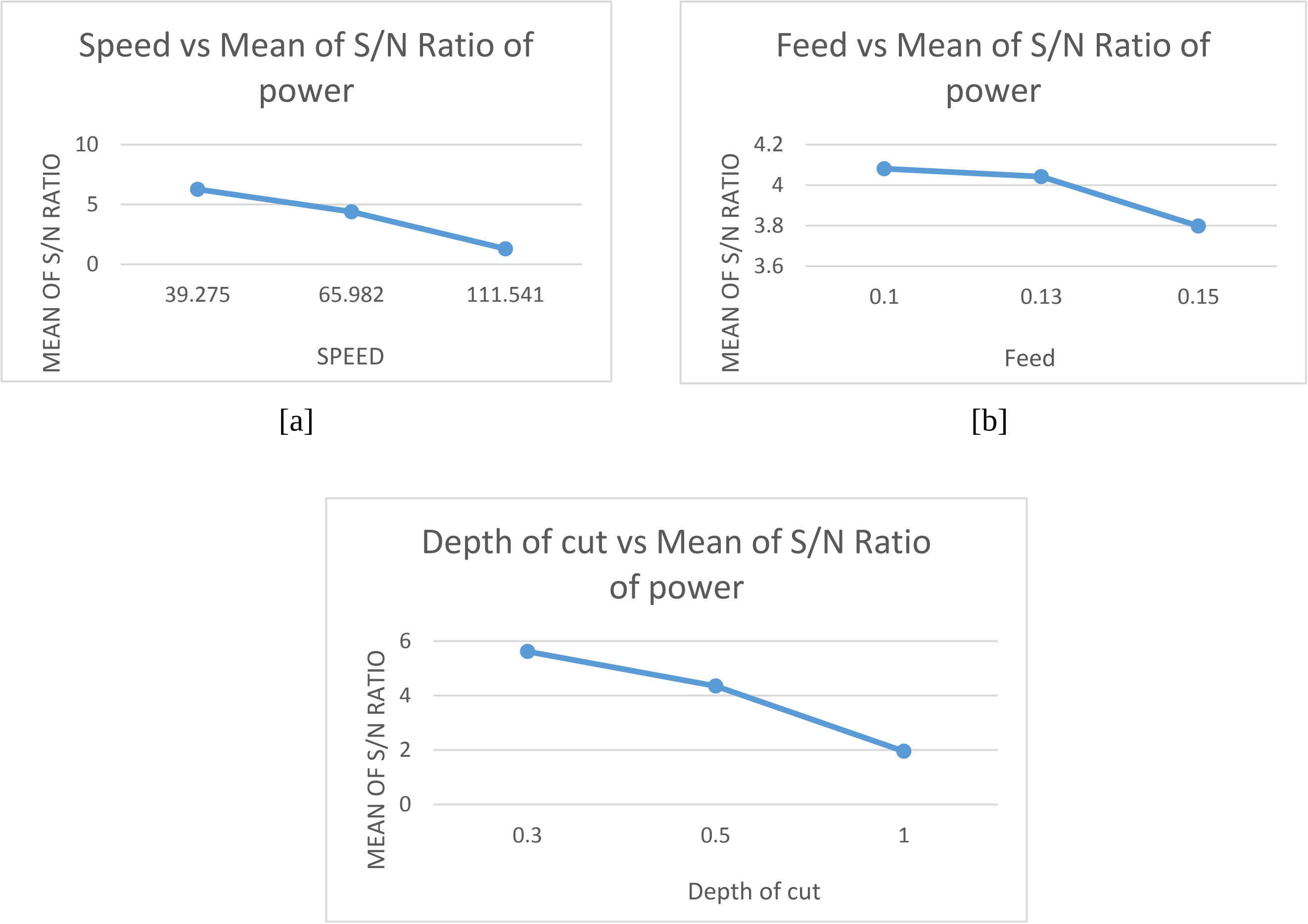


[c]

Fig-5.1

5.2. Main effect diagram of power consumption:-

Figure-5.2(a), (b) and (c) given below shows the main effect plots for power consumption in machining for lower is better. Figure-5.2(a) shows the graph of speed vs. mean of S/N ratio of power consumption. From the graph it is clear that as the speed increases the power consumption decreases. Figure-5.2(b) shows feed vs. mean of S/N ratio for power consumption. The graph shows that as the feed increases the power consumption decreases. Figure-5.2(c) shows depth of cut vs. mean of S/N ratio of power. The graph shows that as the depth of cut increases the power consumption decreases. Out of three graphs the slope of cutting speed vs. mean of S/N ratio has largest slope and depth of cut vs. mean of S/N ratio has the second largest slope so cutting speed and depth of cut significantly affect the power consumption but feed has no significant effect on power consumption.



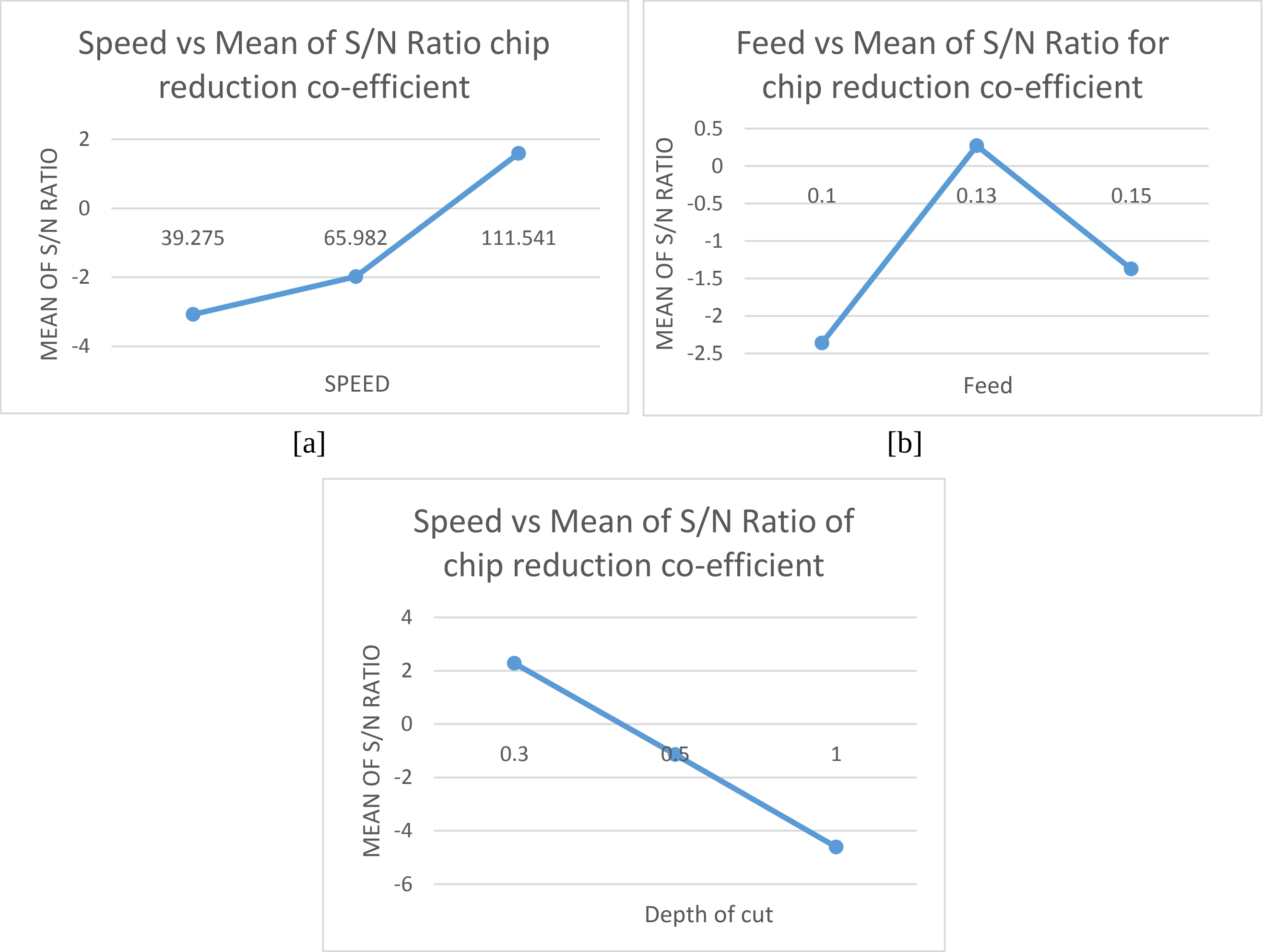
[a] [b]

[c]

Fig-5.2

5.3. Main effect plot of chip reduction co-efficient:-

The figure-5.3(a), (b), (c) given below shows the main effects of chip reduction co-efficient. The figure5.3 (a) shows the graph of speed vs. mean of S/N ratio of chip reduction co-efficient for lower is better. As the speed increases the mean of S/N ratio increases that means chip reduction co-efficient becomes more. The graph in 5.3(b) shows the graph between feed vs. mean of S/N ratio of chip reduction co-efficient. As the feed increases the mean of S/N ratio increases first and then decreases. The graph in 5.3(c) shows the graph between depth of cut vs. mean of chip reduction co-efficient. From this graph it is clear that as the depth of cut increases the mean of S/N ratio decreases. Out three graphs the 5.3(c) graph has the largest slope, 5.3(a) graph has second largest slope so depth of cut and cutting speed have the significant effect on chi reduction co-efficient but feed has not any significant effect.



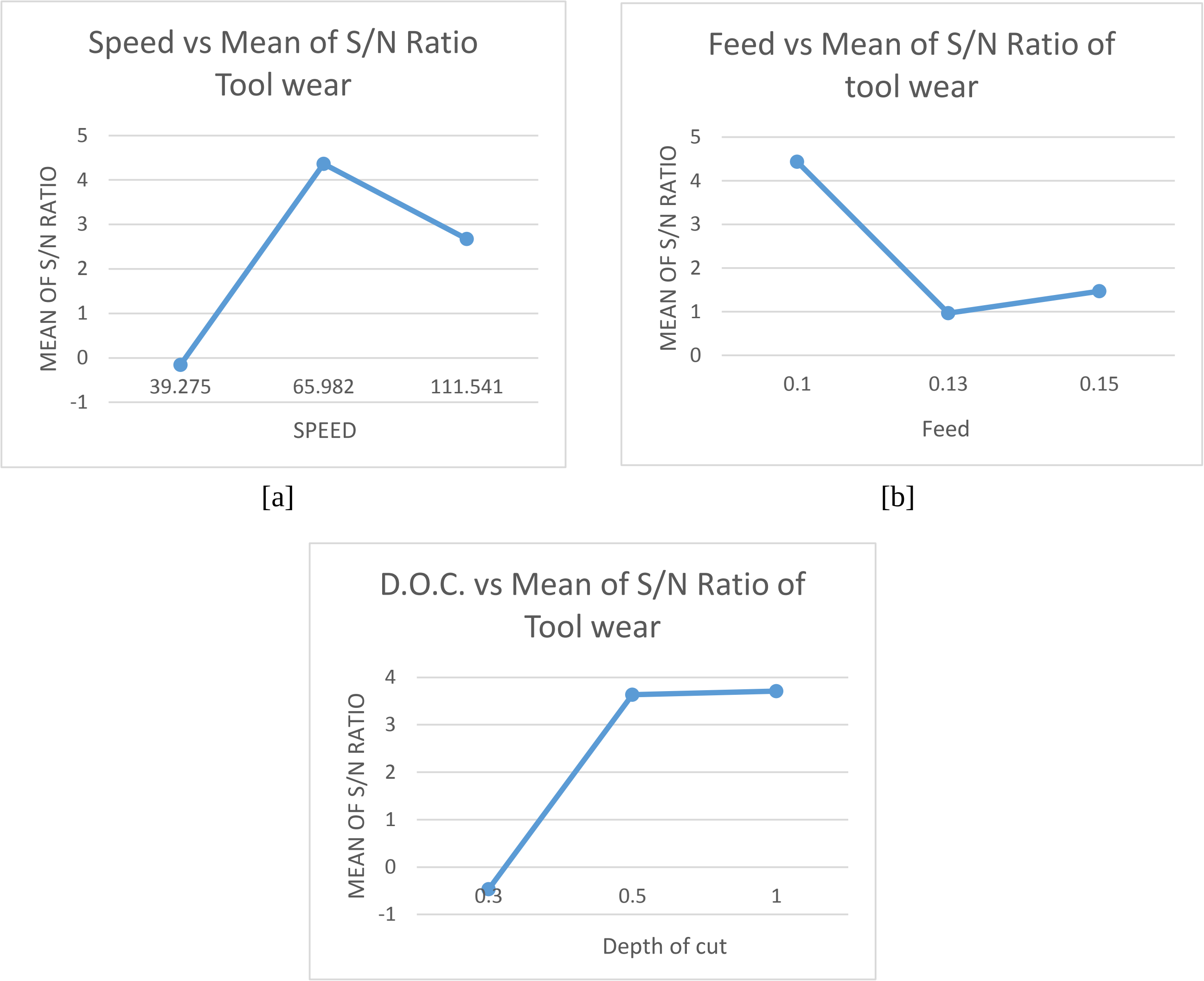
[a] [b]

[c]

Fig-5.3

5.4. Main effect diagram of tool wear:-

The figures given in 5.4(a), (b), (c) shows the main effect diagrams of tool wear for lower is better. The 5.4(a) shows speed vs. mean of S/N ratio of tool wear. The graph shows that as the speed increases the tool wear increases first after some speed tool wear decreases. Out of three graphs the slope of 5.4(a) is largest, slope of 5.4(c) is second largest so tool wear is affected by speed and depth of cut significantly but feed has not any significant effect on tool wear.



[a] [b]

[c]

Fig-5.4

5.5. Anova and response table for surface roughness:-

The anova table for surface roughness shows DF, SS, MS, F- value, P- value. From F-statistics it is clear that feed and depth of cut are significant. Cutting speed has not any significant effect on surface roughness. The response table shows that the rank of feed is one and rank of depth of cut is two that means feed and depth of cut has significant effect on surface roughness. Table-5.1 shows the Anova table for surface roughness and Table-5.2 shows the response table for surface roughness.

Table-5.1:-(ANOVA for surface roughness)

Source	DF	Seq. SS	Adj SS	Adj MS	F	P
V	2	82.41	82.41	41.20	1.20	0.349
F	2	171.56	171.56	85.75	2.51	0.143
D	2	123.87	123.87	61.93	1.81	0.225
V*f	4	134.48	134.48	33.62	0.98	0.469
V*d	4	147.50	147.50	36.87	1.08	0.428
f*d	4	178.82	178.82	44.71	1.31	0.346
Residual error	8	273.91	273.91	34.24		
Total	26	1112.55				

Table-5.2(Response table)

Level	Speed	Feed	Depth of cut
1	0.4176	2.2645	-0.5688
2	-0.6112	-2.9232	-4.2060
3	-3.6942	-3.2290	0.8871
Delta	4.1117	5.4936	5.0931
Rank	3	1	2

5.6. Anova and response table for power consumption:

The table-5.3 shows the anova table for power consumption and table-5.4 shows the response table for power consumption. The ANOVA table shows DF, SS, MS, F-value, P-value. The F-statistics shows that cutting speed and depth of cut are significant. Also p-values for speed and depth of cut are less than 0.05. The delta statistics in response table shows the rank of cutting speed is one and depth of cut is two that means cutting speed and depth of cut are significant.

Table-5.3(ANOVA for power consumption)

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
V	2	113.444	113.444	56.7221	54.04	0.000
F	2	0.419	0.419	0.2096	0.20	0.823
D	2	62.341	62.341	31.1705	29.70	0.000
V*f	4	1.471	1.471	0.3676	0.35	0.837
V*d	4	9.184	9.184	2.2961	2.19	0.161
f*d	4	2.865	2.865	0.7162	0.68	0.624
Residual error	8	8.397	8.397	1.0496		
Total	26	198.121				

Table-5.4(Response table for S/N ratios of power)

Level	Cutting speed	Feed rate	Depth of cut
1	6.260	4.080	5.614
2	4.373	4.041	4.355
3	1.287	3.799	1.951
Delta	4.973	0.282	3.633
Rank	1	3	2

5.7. ANOVA and Response table for chip reduction co-efficient:-

The table-5.5 and table-5.6 shows the ANOVA and response table for S/N ratio of chip reduction co-efficient. The ANOVA for chip reduction co-efficient shows DF, SS, MS, F, P value. The P-value for depth of cut and cutting speed are less than 0.05 so they significant. Table-5.6 shows the response table for chip reduction co-efficient. The delta statistics shows the rank of feed as one and rank of cutting speed as two means they are significant.

Table-5.5(ANOVA for chip reduction co-efficient)

Source	DF	Seq.SS	Adj. SS	Adj. MS	F	P
V	2	107.47	107.47	53.734	8.99	.009
F	2	31.84	31.84	15.922	2.66	.130
D	2	214.32	214.32	107.160	17.93	.001
V*f	4	69.37	69.37	17.342	2.90	.093
V*d	4	45.24	45.24	11.311	1.89	.205
f*d	4	37.83	37.83	9.457	1.58	.269
Residual error	8	47.81	47.81	5.976		
Total	26	553.88				

Table-5.6(Response table for S/N ratio)

Level	Cutting speed	Feed rate	Depth of cut
1	-3.0784	-2.3598	2.2918
2	-1.9764	0.2731	-1.1415
3	1.5958	-1.3724	-4.6094
Delta	4.6742	2.6329	6.9012
Rank	2	3	1

5.8. ANOVA and response table for tool wear:-

The table-5.7 and table-5.8 shows the ANOVA and response table for S/N ratios of tool wear. The table-5.7 shows the ANOVA table for tool wear which contains DF, SS, MS, F, P value.

The F- statistics as well as p-value shows that depth of cut and cutting speed are significant. The response table also agrees with that result.

Table-5.7(ANOVA for tool wear)

Source	DF	Seq.SS	Adj.SS	Adj.MS	F	P
V	2	93.73	93.73	46.866	4.31	0.054
F	2	63.29	63.29	31.644	2.91	0.112
D	2	102.52	102.52	51.262	4.71	0.044
V*f	4	223.90	223.90	55.974	5.15	0.024
V*d	4	170.03	170.03	42.508	3.91	0.048
f*d	4	34.56	34.56	8.64	0.79	0.561
Residual error	8	87.00	87.00	10.875		
Total	26	775.04				

Table-5.8(Response table)

Level	Cutting speed	Feed rate	Depth of cut
1	-0.1564	4.4378	-0.4633
2	4.3595	0.9680	3.6320
3	2.6732	1.4705	3.7076
Delta	4.5159	3.4697	4.1710
Rank	1	3	2

CHAPTER-6

CONCLUSION AND FUTURE WORK

6.1.Based on experimental results presented and discussed, the following conclusions are drawn on the effect of cutting speed, feed and depth of cut on the performance of Tic coated carbide tool when machining Cr-Mo alloy.

1. The study of Main effect plots of surface roughness indicates that as speed increases mean of SN ratio decreases that means good surface finish is obtained with increase in speed. As the feed increase mean of SN ratio decreases that means good surface finish is obtained with increase in feed. As the depth of cut increases from 0.3mm to 0.5 mm surface roughness decreases but when depth of cut increase from 0.5 mm to 1 mm surface roughness increases.
2. The slope of feed vs. mean of SN ratio is largest, depth of cut vs. mean of SN ratio has the second largest slope so feed and depth of cut affect the surface roughness significantly which is clear from F-statistics of ANOVA and rank of response table. So feed and depth of cut are dominant factors for surface roughness.
3. As the speed increases SN ratio for power decreases. As the feed and depth of cut increases also SN ratio for power decreases that means less power is consumed for increase of speed, feed and depth of cut.
4. Cutting speed and depth of cut are significant factors in case of power.
5. As the speed increases mean of SN ratio increases that means chip reduction co-efficient becomes more when speed increases. As feed increases from 0.1 to 0.13 chip reduction co-efficient increases and from 0.13 to 0.15 chip reduction co-efficient decreases. As the depth of cut increases chip reduction co-efficient decreases.
6. The depth of cut and speed affect significantly chip reduction co-efficient.

7. When speed increases from 39.275 m/min to 65.982 m/min tool wear increases and from 65.982 m/min to 111.541 m/min tool wear decreases. When feed increases from 0.1 to 0.13 mm/rev tool wear decreases rapidly but from 0.13mm/rev to0.15 mm/rev tool wear increases slowly. When depth of cut increases from 0.3mm to 0.5 mm tool wear increases, from 0.5 mm 1.0 mm it remains constant.
8. Tool wear is affected significantly by cutting speed and d.o.c.

6.2.Future work:-

1. In the present work chrome-moly alloy steel is used for machining process so in future work other hard materials like Inconel-718 can be used for machining by the same process varying speed, feed and depth of cut in L-27 orthogonal array design and taguchi method may be used for analysis.
2. Some other cutting inserts like ceramic or CBN may be used for cutting instead of coated carbide insert and the experiment may be repeated insame way the result may be compared with previous result.
3. Rsm may be used for analysis process instead ofTaguchi method.

CHAPTER-7

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