NUMERICAL ANALYSIS AND EXPERIMENTAL INVESTIGATION OF TURNING OPERATION USING SOLID LUBRICANT

By

Chetan U Hingane

15MMCC07

DEPARTMENT OF MECHANICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481
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NUMERICAL ANALYSIS AND EXPERIMENTAL INVESTIGATION OF TURNING OPERATION USING SOLID LUBRICANT

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(CAD-CAM)

By

Chetan U Hingane

(15MMCC07)

Guided By

Prof. Mayur M Makhesana

DEPARTMENT OF MECHANICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481
May 2017

Declaration

This is to certify that

1. The thesis comprises of my original work towards the degree of Master of Technology in Mechanical Engineering (CAD-CAM) at Nirma University and has not been submitted elsewhere for a degree.

2. Due acknowledgment has been made in the text to all other material used.

Chetan U Hingane

15MMCC07

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Prof. Mayur Makhesana
Internal Guide,
Department of Mechanical
Engineering,
Institute of Technology,
Nirma University,
Ahmedabad.

Dr. R N Patel
Professor and Head,

Department of Mechanical
Engineering,
Institute of Technology,
Nirma University,
Ahmedabad

Dr. Alka Mahajan
Director,

Institute of Technology,
Nirma University,
Ahmedabad

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Chetan U Hingane

15MMCC07

Abstract

Machining of material is one of the basic need of manufacturing industries. Turning operation is rudimentary process in machining. Many industries and researchers are working in a direction to improve quality and quantity of the product at the same time. Cutting speed, Feed and Depth of cut are cardinal process parameters to determine the quality and quantity of the product produced in process. Turning operation is a material removal process. Considerable amount of heat is generated in meal removing process. Surface finish and heat generated during the process are influenced by process parameter. In turning operation heat generated is one of the cause for poor quality of product produced and tool wear. Various cooling techniques are used to control heat generated during the process.

In present work effect of cooling techniques and each process parameter were observed for the surface finish and heat generated during the turning operation. Effects of feed, depth of cut and cutting speed were observed as well as effect of minimum quantity lubricants (MQL) with solid lubricants were investigated. Experiments were performed on KIRLOSKAR TURNMASTER 35 lathe machine with CNMG120404 grade TN2000 tool. Graphite and molybdenum disulfide were selected as solid lubricants. Tool-chip interface temperature measurement by conventional method is expedient. Complete setup of tool-work thermocouple was made on late machine. Calibration of thermocouple was done using hot air oven and oxy-acetylene flames. Design of experiment was done using response surface methodology (optimal) to acquire trials of experiment. For all different cutting condition set of trials were iterated. From the acquired results mathematical model was made. Post analysis was done using Design expert 10 (Response surface methodology). Combined and individual effect of process parameter were observed for each trials of experiment. To validate the mathematical model, simulation for turning operation were performed on ANSYS workbench 16.2.

It was found that feed is the most influential process parameter for surface finish produced and temperature generated at tool-chip interface is influenced by depth of cut. Heat generated at tool-chip interface and Surface finish of the product is more satisfactory in case of machining with molybdenum disulfide.

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Nomenclature

F	Feed
D	Depth of cut
V	Cutting speed
Ø	Diameter
MQL	Minimum quantity Lubricant
P	Power
I.P	Ideal power
S.R	Surface roughness
S.F	Surface Finish
T	Temperature

Chapter 1

Introduction

1.1 Machining

In today's industrial market machining is very important part of manufacturing system. Metal cutting by different means of machining is used in industries as per there requirements. In general machining can be defined as any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. Major machining processes with material removal used in industries are Turning, Shaping, Milling, etc. Machining process are selected according to the final shape of the product or operation to be performed on the product. Removal of flat surfaces, producing straight or angular grooves is done by milling operation. Machining of flat straight, flat surface, but with ingenuity and some accessories a wide range of work can be done by shaping operation. Cylindrical workpieces and operations like Drilling, boring, knurling, reaming, threading are performed using turning operation.

In this project turning operation and parameters affecting the quality of the product in terms of its surface integrity are going to be focused. In today industrial world production rate plays very important role, quality of the product produced in the process should be justified with the quantity produced in the production cycle. For higher production rate it is important to arrange process parameters accordingly, generally in such cases difficulties like tool failure, low surface finish, high temperature generation and many other effects are faced which directly or indirectly reduces quality of the product. In case of turning operation, parameters affecting the quality and quantity of the product produced are cutting speed, feed and depth of cut, increasing any of this parameters can improve production rate. During turning operation if value of any of the process parameter is increased it increases the temperature in cutting region, which leads to poor surface finish and high tool wear. Lubricants are used to overcome this problem, they helps to reduce friction between tool and workpiece hence there is less heat generated at tool-workpiece interface. As lubricant are good conductor of heat, large amount of heat is dissipated to environment. Hence temperature is reduced by considerable amount[1]. Using lubricants higher cutting speed, feed and depth of cut can be used [2]. Variety of lubricants which possess different type of material properties are available. In this project work for enhancing turning operation, solid lubricants will be used. A lot of research work is done on using of solid lubricants as cutting fluid in machining of metals [3], but still significant results are not obtained.

1.2 Machining Process

Machining is a process in which cutting tools are used to remove material from the workpiece. Removal of material is in the form of chip formation, to form chip from the material relative motion is required between tool and workpiece. Relative motion is achieved by two types of motion, Primary motion in form of cutting speed and secondary motion in form of the feed. Primary and secondary motion combined with the shape of tool and its penetration in the workpiece results in the desired shape and size of the work surface[4]. Quality of the product produced depends and all the input parameters[5].

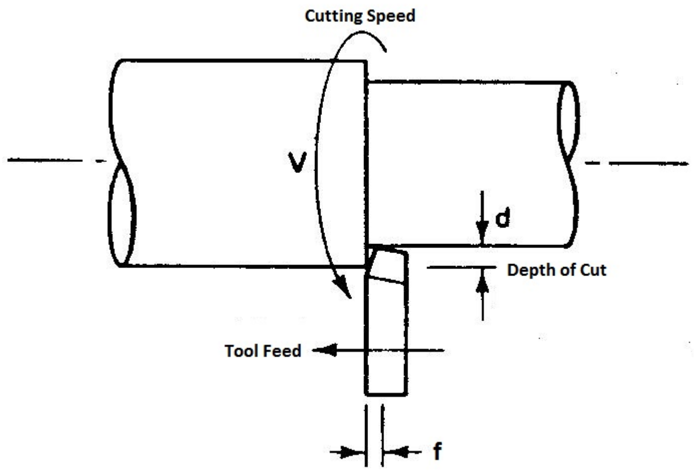


Figure 1.1: Relative Motion[7]

Material removal in form of chip is possible when uncut layer of the work material only in front of the cutting tool is subjected to all sided compression, the force applied by the tool on the chip emerges out of the normal force, and frictional force. Shear stress is developed due to high compression within that compression region, forces are generated in different magnitude, different directions and they there magnitude increases rapidly. Whenever the value of shear stress produced in compression region exceeds the shear strength of the work material, yielding takes place resulting in formation of chip. As chips is formed forces causing shear stress disappears. As the forces start disappearing when chip starts to flow through the rake surface of tool succeeding portion of the workpiece star undergoing the same action. The cycle keep on continuing which leads to formation of chip layer by layer[6].

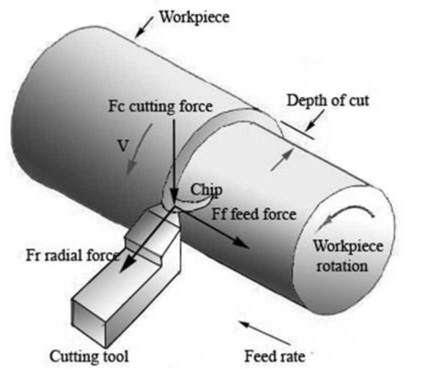


Figure 1.2: Cutting Forces[7]

1.3 Heat Generation

Heat generated during turning operation plays very critical role. It has large impact on the tool wear and surface integrity of the product formed, tool life is reduced by large extent. Heat generated during turning operation is distributed in three different regions, Shear zone (Primary), deformation zone (secondary), worn out of flank (tertiary) [6]. In primary zone heat generated is due to plastic deformation, shear energy is completely converted into heat energy hence major portion of heat generated is in primary zone. In secondary zone heat generated is due to rubbing between chip and rake surface of tool, heat generated in this region is very low as compared to primary zone therefore in many cases it is neglected. In tertiary zone heat generated is due to rubbing of tool and finished surface of the workpiece, heat generated in this regions effects surface finish of the product produced.

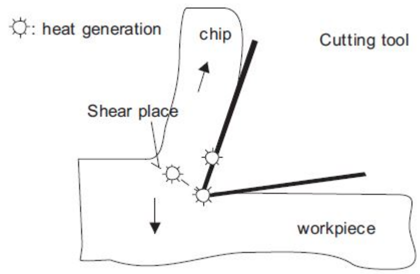


Figure 1.3: Heat generation[7]

1.4 Solid Lubricants

Solid lubricants are also known as dry lubricants. Solid lubricants are materials which helps in reducing friction between two sliding surfaces, solid lubricants do not require any kind of liquid oil phase they provide lubrication in solid phase only. The two main solid lubricants are graphite and molybdenum disulfide. It has been trusted that extraordinary conditions like higher pressure and temperature are exceptionally remarkable, however about every industry having least one such sort of process in which the machining procedure could be portrayed as outrageous condition from a lubrication perspective. At this condition fluid lubricants couldn't sufficiently play out the entire procedure, whereas solid lubricants can perform extremely well in such conditions. Solid lubricants can work at very high temperature range and also in vacuum conditions. They are generally used where long term lubrication are required without re-lubrication and where contamination is not allowed [2]. This material are used in combination with other agents and metals like copper, lead etc. or independently to obtain required results. Solid lubricants such as graphite, molybdenum disulfide etc. possess crystal lattice structure, they are used as stand-alone lubricants. Due to crystal lattice structure of solid lubricants they have very low shear force between there lattice layers, hence lamellar lattice layers slides over each other with application of small force on it therefore they reduces friction between sliding surfaces by significant amount. Main advantages of solid lubricants over liquid lubricants are, they can work under High temperature, Extreme contact pressure, intermittent loading condition, inaccessible location and where contamination is to be avoided. Solid lubricants are used in turning operation by various methods. Spraying, dipping, brushing, free powder, anti-friction coating and dispersion are methods of application that can be used in turning for use of solid lubricants[19].

1.5 Cutting Tool

Cutting tool are devices which are used to remove material from the workpiece. Cutting tool are categorized as single point cutting tool, multiple point cutting tool, reamers, drills etc. Each tool is designed as per its working condition and for its manufacturing process. This tool are used to removal material from the workpiece by shear deformation which results in fracture failure of the workpiece material and formation of chip. To perform machining, different tools are used for different process, depending on the process to be carried out. To select proper tool for proper machining it is required to take care of some factors such as.

- Shape of the product to be produced.
- Hardness, tensile strength, abrasiveness, ductility of the workpiece material.
- Type of chip generated.
- Heat generated during the process.

Cutting tool geometry should be selected as per requirement. In turning operation generally single point cutting tools are used. In many cases multiple point cutting inserts are used, in this cases also Only single cutting edge is used for machining as the tool edge get wear out another edge is used. Some important tool geometry are shown in figure. For different machining process different kind of tool geometry are used as for good surface finish too with less nose radius is used, for high strength of tool with negative rake angle is used. For different requirement different tools geometry are used

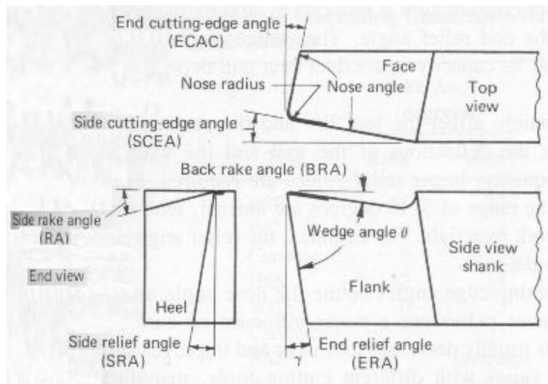


Figure 1.4: Tool Geometry[7]

Chapter 2

Literature Review

2.1 Review of published paper

Xavior and Adithan [1] has studied the influence of cutting fluids on tool wear and surface roughness during turning of ANSI 304 with carbide tool. They compared effect of coconut oil as cutting fluids with emulsion and neat cutting oil. The Significant parameters influencing the surface roughness and tool wear were found using ANOVA procedure. By developing multiple linear regression models for flank wear and surface roughness (Minitab-15) a mathematical software was developed. It was found that feed rate has greatest influence on surface finish and cutting speed has greatest influence on tool wear. Among three lubricants coconut oil was found to be best lubricant for reducing tool wear and surface roughness.

Reddy and rao [2] investigated the effect of solid lubricant on machining process with high material removal rate. They compared the experimental result of machining with solid lubricants and conventional cutting fluids. Solid lubricants used for the experiments were graphite and molybdenum disulfide. the effect of process parameter and tool geometry was also evaluated. Tool of different radial rake angle and nose radius were used in experiments. It was concluded that there is no such improvement in machining process with solid lubricant as compared to conventional lubricants.

Singh and Rao [3] worked on enhancing surface quality by solid lubricant in hard turning. In that review MoS2 solid lubricant utilized as another option to cutting fluid to diminish the grating and utilizing that solid lubricant the surface complete additionally enhanced of bearing steel. To concentrate the solid lubricant conduct on Ra amid the machining the central composite outline was utilized. Result originate from these was that the execution enhanced in the machining zone when MoS2 solid lubricant was utilized furthermore enhanced machinability with noteworthy change in surface quality.

Suri et al. [4] has studied the effect of minimum quantity lubrication (MQL)/near dry machining (NDM), high pressure coolant (HPC), cryogenic cooling, compressed air cooling and use of solid lubricants for reduction in friction and heat at the cutting zone. Tests were conducted to obtain flank wear. ANOVA was used to obtain important parameter affecting heat generation. Surface characteristic, tool wear, fluid aerosol generation under different cooling condition was predicted using mathematical model and application of FEA techniques. From experiments and analytical results it was concluded that material having low machinability can be machined with cryogenic cooling which helps in increasing tool life without compromising on the environmental conditioning. It was concluded that at higher cutting speed performance of solid lubricant is better that other lubricants.

Monika et al. [5] studied the effect of dry and wet turning. External turning on EN31 material was performed with tungsten carbide insert tool. Effect of Feed, depth of cut and cutting speed on turning operation in both operation were observed. Surface roughness, process temperature, power consumption and tool wear results obtained from both environment were compared. It was concluded that using wet environments leads to 20 to 30% reduction in process temperature, there is lower power consumption in wet environment. Tool wear is reduced significantly, which leads to better surface finish as compared to dry cutting.

Kashiway [6] explored the impact of cutting temperature on workpiece surface.

It had been demonstrated that cutting temperature affected the integrity over the machined surfaces. The undesirable surface tensile Rs were influenced to the TC which was produced amid the machining procedure. So that to control the produced tensile stresses on the comprehension of the impact of parameters on the cutting temperature.

Schubert and Nestler [8] has done work to improve surface finish and stress condition in shear zone in machining of Aluminum matrix composites (AMC's) by modifying tool geometry. Machining was done by several wiper geometry CVD diamond tipped insert. Wiper geometry tools were used to obtain better surface finish. For experiment only feed was varied keeping all other parameters constant, each parameter chosen was tested thrice. Experimental readings concluded that tools with large wiper radius or trailing edge are particularly good for generating surface with small roughness values. Void can be reduced by using tool with a flank wear land width of approximately 100 µm.

Mantle et al. [9] has checked the performance of various range of polycrystalline diamond tools (PCD) for turning of Ti-6Al-2Sn-4Zr-6Mo with pressurized cutting fluid of 150bar. Five different grades of PCD insert tools were used. Tools were differentiated by their grain size. Flank wear was taken as end criteria for test keeping all other parameters constant. From experimental readings it was found that tool with grain size of approximately 14 µm leads to increase in tool life.

Silberschmidt et al. [10]investigated effect of vibration on cutting forces and temperature levels in cutting region for different cutting conditions. Low energy high frequency vibration was superimposed on tool movement using ultrasonic assisted turning (UAT). Dry machining was done to obtain all experimental readings. Using MSC MARC/MENTAT 3D thermo-mechanically coupled finite element method of cutting tool and ultrasonic assisted turning was developed. At tool-workpiece interface friction behavior was simulated using Modified Shear Friction Law. Tangential component of cutting forces were reduced by 69%. From experimental reading it was found that UAT technique is more effective at higher depth of cut and for cutting speed beyond 60 m/min cutting forces vanished. It was concluded that UAT can offer higher material removal rate as compared to conventional turning up to five times.

Krishnaa and Rao [11] has studied application of Solid lubricant mixtures like graphite and boric acid in SAE 40 oil in turning of EN8 steel. Graphite and boric acid in proportion of 5%, 10%, 20%, 30%, and 40% by weight are mixed with SAE 40 oil for testing there lubricating and cooling properties. For each sample experiments were conducted keeping process parameters same. All samples were tested for same cutting conditions, from experimental reading it was concluded that with increase in solid lubricant content in SAE 40 oil mixture exhibits increase in kinematic viscosity and decrease in thermal conductivity which leads to improve the process. Flank wear and cutting forces were reduced because of a solid lubricant film on the surface.

Ram and Yadav[12] has done detailed study on CNC lathe machine using response surface methodology as design of experiment for turning operation. Response variable were surface roughness and material removal rate. Effect of process parameter on response variable were observed. Optimization of response variable was carried out. Significant parameters affecting response variable were obtained using ANOVA. Mathematical model was made to compare the value of experimental readings. Values of response variable were predicted using mathematical model and it was found that the values predicted and experimental values are within five percentage limit. It was concluded that mathematical model developed can be used to evaluate surface roughness and material removal rate directly. It was observed that feed rate is least effective parameter for both surface finish and material removal rate whereas spindle speed is most effective parameter for surface finish and depth of cut is most effective for material removal rate.

Chaudhari and hashimoto [13] has studied the effect of different tool geometry on surface finish of the product produced by turning operation and they observed variation on cutting forces due to tool wear. Experiments were conducted to obtain evolution of flank wear and its effect on surface integrity and residual stress produced. Experiment was conducted under constant cutting conditions for short cutting time to observe accurate evolution of flank wear and resulting cutting forces. From experimental reading it was observed that normal and tangential forces are directly proportional to flank wear, but after certain amount of flank wear value of normal forces increases rapidly. Re-tempering of workpiece was confirmed by visibility of dark layer covered by a milky layer. Compressive stresses were observed when machining was done by new insert whereas with increase of flank wear lead to formation of tensile stresses at shallow region beneath the surface. Useful tool life can be defined by the discontinuity in relationship between normal and tangential forces. Discontinuity can be predicted by the ratio of normal to tangential force.

Sullivan and Cotterell [14] has measured reaction forces and temperature during turning operation. They also observe the effect of cutting forces on surface temperature. Temperature was measured using a welded tip PTEE insulated K-type thermocouples and Inframetric termacan infrared thermal imagining camera. Measurement of forces was done by Kistler quartz four component dynamometer. Experimental reading were taken by machining Aluminum alloy with carbide tool. From experimental results it was concluded that cutting forces and machined surface temperature can be decreased with increase in cutting speed. Cutting forces are very important variable in generation of surface temperature. It was also concluded that tool wear resulted in increased cutting forces and machined surface temperature.

Mehul and Bhavsar [15] has worked on obtaining average tool temperature. They also developed mathematical model equation by CCD based on RSM experiment. For experiment quenched and tempered EN36 hardened steel was machined with TN200 grade K20 shim tool was used. For data acquisition Adrino UNO R3 board was used. For data collection and visualization LAB VIEW software was used. To obtain proper temperature readings thermocouple was placed just right side of insert through hole made at right side of shim. Three parameters with three level were selected to perform experiment. ANOVA was used to study effect of each parameter on cutting temperature. Experimental finding validates mathematical model developed as error in temperature measurement was less than 10 percentage. To obtain minimum temperature during machining of EN36 optimized values of process parameter have been achieved with desirability of 98.9 percentage.

Abhang and hameedullah [18] evaluate the influence of process parameter on tool chip interface temperature. Influence of feed, depth of cut, cutting speed and nose radius was observed. Temperature of tool-chip interface was calculated using tool-work thermocouple. Setup of tool-work thermocouple was made. For calibration of thermocouple similar setup was made, using oxy-acytelene flames hot junction of thermocuple was heated and thermo-electric relations for thermocouple was calculated. It was found that cutting speed, feed, depth of cut are the most influencing parameters. Increase in cutting speed, feed and depth of cut increases tool-chip interface temperature whereas increasing the tool nose radius helps in reducing the tool-chip interface temperature.

Byrne [22] evaluated average interfacial temperature generated in turning of various metal experimentally using by Herbert/Gottwein dynamic thermocouple method. HSS tools were used to machine mild steel, aluminum, brass and stainless steel. Calibration by furnace method was done to evaluate the thermoelectric relation between HSS and each metal. Influence of cutting tool condition on the emf generated was investigated as well as AC and DC component of emf were explained. Extensive range of process parameter for all individual material were selected to obtain results for interfacial temperature. For wide range of interfacial temperature results were presented and discussed.

2.2 Summary

From above review of research papers it can be concluded that machining process can be enhanced in terms of the quality of the product produced as well as improved production rate. It is the time to improve methods of conventional machining in terms of cutting parameters and lubrication method. From the data it can be concluded that proper use of solid lubricants can help in reducing friction between tool workpiece interface and also in cooling which leads to better surface integrity of the workpiece. Wiper tool geometry can be used to increase surface finish, using proper process parameters it is possible to reduce rate of flank wear which can improve useful tool life and surface integrity. From available solid lubricant molybdenum disulfide in better solid lubricant than other lubricants in terms of reducing friction and cooling tool-workpiece interface. For design of experiment response surface methodology can be used for each lubricant separately. Use of thermocouple and thermal imagining cameras are advisable to observe temperature at tool-workpiece interface and cutting forces can be calculated using load cells and amplifier. Development of mathematical model is possible using various software. Validation of mathematical model should be done by comparing readings with experimental data.

Chapter 3

Heat Generation

Heat generated during machining plays very important role in the quality of product formed and tool wear. Heat generated leads to deformation of tool and workpiece as well as it causes environmental problems. Heat generation varies in different machining operation, Heat generation depends on the process parameters used during machining operation. Process parameters like cutting speed, depth of cut and feed rate has great influence on heat generation. Heat generated during turning operation is basically due to two reasons, shear deformation and friction between sliding surfaces. Chip formation in turning operation occurs due to the plastic deformation of the material in workpiece. Nearly all energy input required for shear deformation is converted into heat energy. There are two shear deformation region in turning operation which are shown in figure. Heat generated due to friction is at tool-chip interface and tool-workpiece interface. Major portion of Heat generated is at primary shear zone.

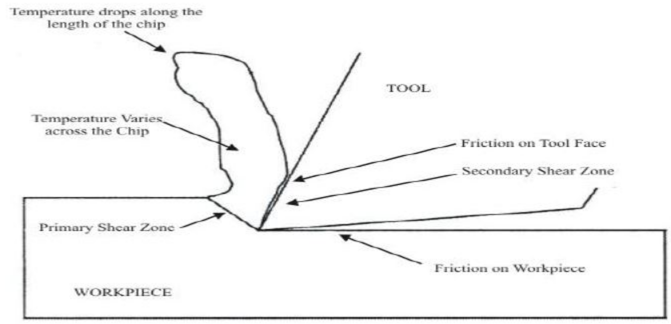


Figure 3.1: Heat Generation Zone[7]

Major amount of heat generated during machining operation is carried out by means of solid lubricant, part of heat is carried away by chips formed during the machining operation. Remaining heat is transferred to tool and machined surface. Heat transferred to tool and machined surface leads to temperature rise of tool tip and surface. Increased temperature at tool tip leads to poor surface finish of the machined surface. There are chances that due to heat generated, chip formed during machining operation can get welded on the tool or workpiece which has impact on the quality of the product formed.

3.1 Heat transfer

Heat generated during machining operation propagate to environment, tool and workpiece by conduction, convection and radiation. Heat generated at the interface of tool-workpiece and tool-chip is propagated to workpiece and chip by conduction. Heat is transferred from tool to tool holder by conduction. Heat carried away by cutting fluid and air from heat generation zone is by convection. In machining process heat transfer by mean of radiation is negligible when cutting fluids are used, in absence of cutting fluid (Dry machining) heat is radiated from tool and workpiece to environment. As heat propagates in various ways in heat generation it is necessary to know in which manner heat is distributed at cutting zone. Distribution of heat at cutting zone is shown in figure.

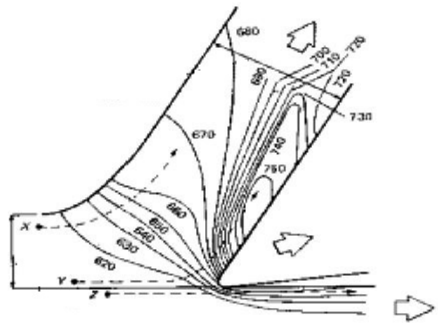


Figure 3.2: Heat distribution at cutting zone[16]

3.2 Influence of cutting fluid

Major amount of heat generated is carried away by means of cutting fluid. Heat generated at the shear zone is conducted to the surface of the tool and workpiece which is carried away by cutting fluid by convection. Cutting fluid also acts as lubricant hence reduces large amount of heat generation. Cutting fluids helps in reducing the temperature at cutting zone by two means.

- Heat is transferred from tool and workpiece by means of convection to cutting fluid.
- Cutting fluid acts as lubricant, it helps in reducing the friction between the tool and workpiece hence heat generated is reduced.

Cutting fluids also helps in reducing machined surface temperature which is very important to obtain high surface finish value during turning operation. It is very important to select proper cutting fluid for proper operation so it can transfer maximum amount heat from cutting zone and provide maximum lubrication so that heat generation can be reduced to some extent. To obtain high surface finish value during turning operation. It is very important to select proper cutting fluid for proper operation so it can transfer maximum amount heat from cutting zone and provide maximum lubrication so that heat generation can be reduced to some extent.

3.3 Effects heat generated

Heat generated during machining operation has great influence on the quality of the product formed. Quality of the product formed depends on the tool condition and influence of heat generated on workpiece material. It is important to select tool material and workpiece material according to the heat generated during operation. Heat generated in cutting zone has separate effects on the tool and workpiece.

3.3.1 Effect on tool

Due to heat generation continuous cutting process there are chances of high temperature at tool tip (Cutting edge). Very less tool life is observed if proper tool material is not selected, due to deformation of tool edge at high temperature. There are chance of formation of built up edges. Tool tip can undergo fracture in form of cracks also. Plastic deformation of tool can lead to permanent failure of the tool and may damage the product.

3.3.2 Effect on workpiece

Heat generated during machining operation majorly occurs in the workpiece. Most of the energy required for plastic deformation is converted in to heat energy in workpiece. Due to heat propagation and high temperature there are wide chances of deformation of the workpiece which lead to dimension inaccuracy of the product. Product form can undergo oxidation, corrosion or burn marks due to high temperature. Surface of the workpiece can undergo damage in form of micro-cracks. Due to temperature distribution and propagation there are large chances of residual stresses which leads to poor product quality.

Chapter 4

Material Selection

4.1 Workpiece material selection

Metal cutting application is growing like a giant elephant in today's industrial world. It has become very important to enhance the machining process to simplify the current status of conventional machining. In this project main objective is to improve product quality and production rate of the process. Material which has low machinability and widely used in industrial area has to be selected. There are many alloy steels and different material which has matching specification as required. From the wide range of material available in the market and there application in industry, AISI 4140 steel has been selected as the workpiece material for the project. It is also known as high tensile steel it is used in manufacturing axles, conveyor parts, crow bars, gears, logging parts, spindles, shafts, sprockets, studs, pinions, pump shafts, rams, ring gear etc. AISI 4140 has wide application in the industries and many of its application does not allow dimensional tolerance, hence machining of such metal should be done precisely. Chemical composition of the material are given in below table.

Table 4.1: AISI 4140 Chemical composition

C	P	S	Si	Mn	Cr	Mo	Ni	Fe
0.386	0.032	0.029	0.377	0.67	1.04	0.091	0.143	Balance

AISI 4140 is a 1 percentage chromium-molybdenum medium hardenability general purpose high tensile steel. It is generally and tempered in the tensile range of 850 to 1000 Mpa. Mechanical and physical properties of AISI 4140 are listed in table below

Table 4.2: Physical properties of AISI 4140[20]

Property	Unit	Value				
Density	kg/dm^3					
Modulus of elasticity	KN/mm^2					
Thermal conductivity	$W/(m.K)$					
Electric resistivity	$Ohm.mm^2/m$					
Specific heat capacity	$J/(kg.K)$					
Modulus of elasticity	KN/mm^2	100 ° C	200 ° C	300 ° C	400 ° C	500 ° C
		205	195	185	175	165
Thermal expansion	$10^6 m/m.K$	100 ° C	200 ° C	300 ° C	400 ° C	500 ° C
		11.1	12.1	12.9	13.5	13.9

Table 4.3: Mechanical properties of AISI 4140[20]

Material	Tensile Strength (Mpa)	Yield strength (Mpa)	Elongation (%)	Izod Impact (J)	Charpy Impact (J)	Brinell Hardness
AISI 4140	850-1000	665	13	54	50	248-302

4.2 Tool Selection

Response variable needed for experiment are surface roughness and temperature at tool chip interface. It is preferred to select a tool for the experiment in such a way that it should help us to obtain precise results. As it is important to work in direction where maximum surface integrity of the product is produced, it is required to select tool insert which is used for finish working. Tool with small nose radius has to be selected. Carbide tools are selected because workpiece material has good tensile strength, yield strength and hardness values. To get precised values from the experiment and keeping all other data in consideration CNMG120404 grade TN2000 as the cutting insert is selected. Insert specification are given in table and figure.

Table 4.4: Tool Insert Specification[21]

Specification	Value
Insert Shape	Rhomboid 80 $^\circ$
Clearance Angle	0 $^\circ$
Tolerance on thickness	± 0.13
Cutting edge length (L10)	12
Thickness	4.76
Nose radius	0.4

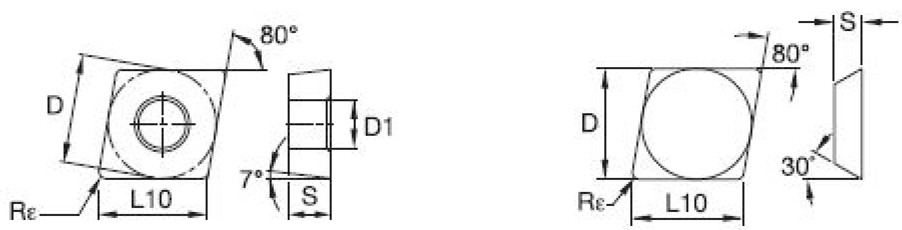


Figure 4.1: Tool insert Geometry[21]

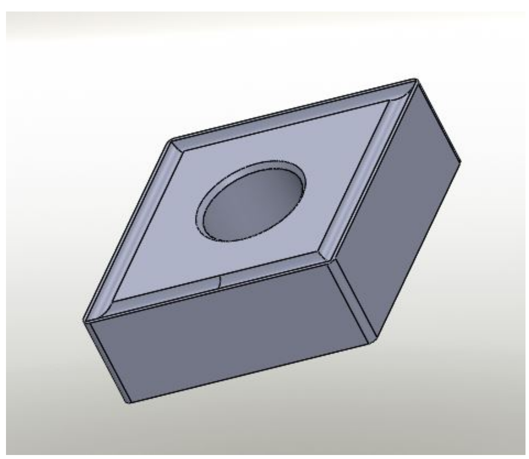


Figure 4.2: Tool cad model

Evaluation of surface roughness and temperature roughness at tool-chip interface is primary motive. Accordingly tool has to be selected. Surface finish of the product depends on the tool geometry and process parameter. Tool geometry with small nose radius is preferred for better surface finish, as selected tool has small nose radius.With small nose radius there are high chances of tool wear. It is important to change the tool after every experimental trials. Selected tool CNMG120404 grade TN2000 has four cutting tips. It is important to use new insert for every set of trials, as there is high probability of tool to get wear out. Blunt tool can lead to improper readings of surface finish and temperature readings.

Chapter 5

Selection of Cutting Fluid

5.1 Type of Cutting fluids.

In recent industrial scenario machining is used worldwide, basic problem faced during machining operation are heat generation in cutting zone. Heat generation is due to shear deformation during cutting and friction between relatively moving surfaces. To overcome this problem many techniques are used. Cutting fluids works as lubricant as well as carry away the heat generated in cutting zone. Some of the techniques used are presented in figure.

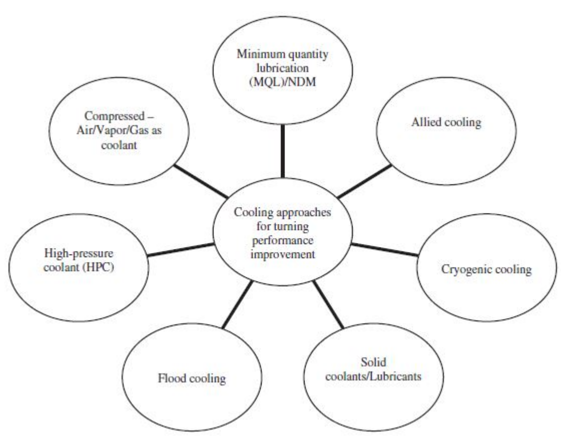


Figure 5.1: Cooling Techniques

In this project MQL and solid lubricants will be used as cutting fluid. Lot of researchers are working on application of solid lubricants in machining process as they are environment friendly and provide excellent lubrication as well as due to good thermal conductivity they provide great cooling effects during cutting operation. Most common solid lubricant used in industries are molybdenum disulfide, graphite, calcium difluoride etc. For MQL mixture of solid lubricant and SAE40 oil will be used as cutting fluid. Performance of solid lubricants are decide by its physical properties and particle size. Refined particle size of lubricant is preferred.

5.2 Solid Lubricants

Scanning electron microscope (SEM) analysis of solid lubricant was done to obtain its particle size for comparison. Molybdenum disulfide, graphite and calcium difluoride were selected for SEM analysis. SEM photographs of lubricants are shown in figure.

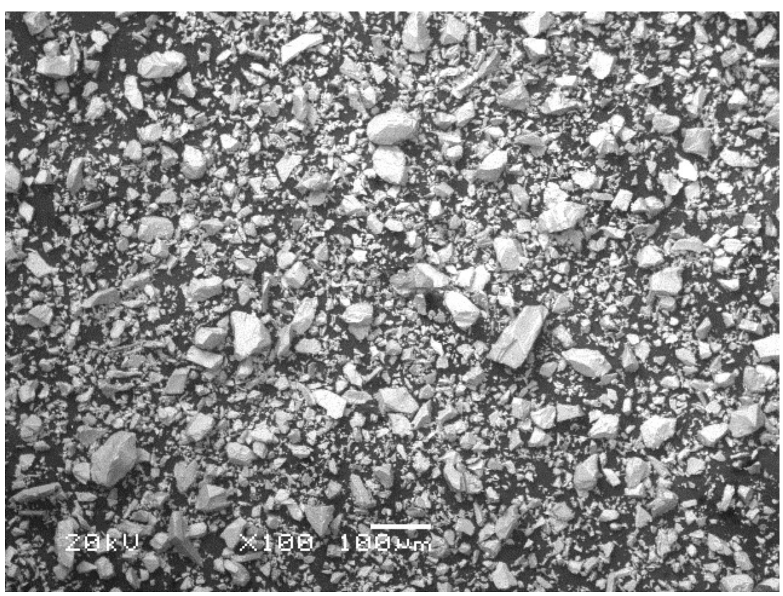


Figure 5.2: SEM CaF2 X100

Figure 5.3: SEM CaF2 X270

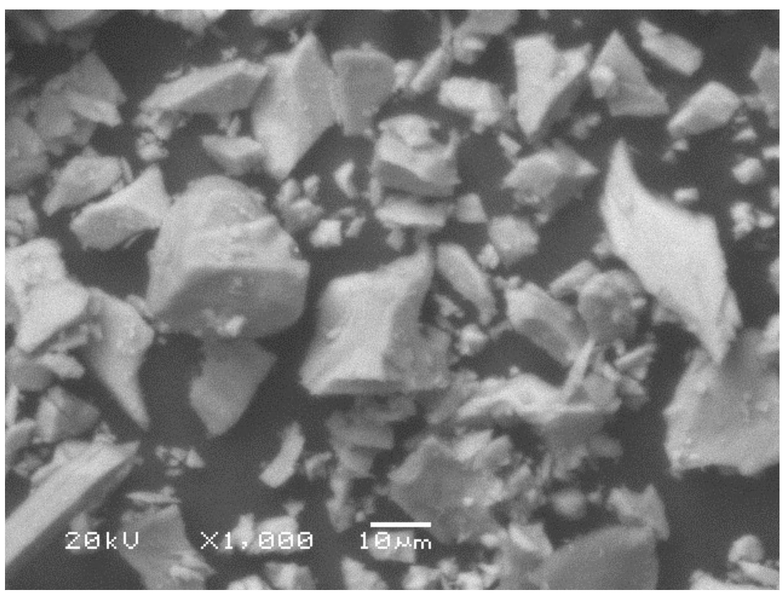


Figure 5.4: SEM CaF2 X1000

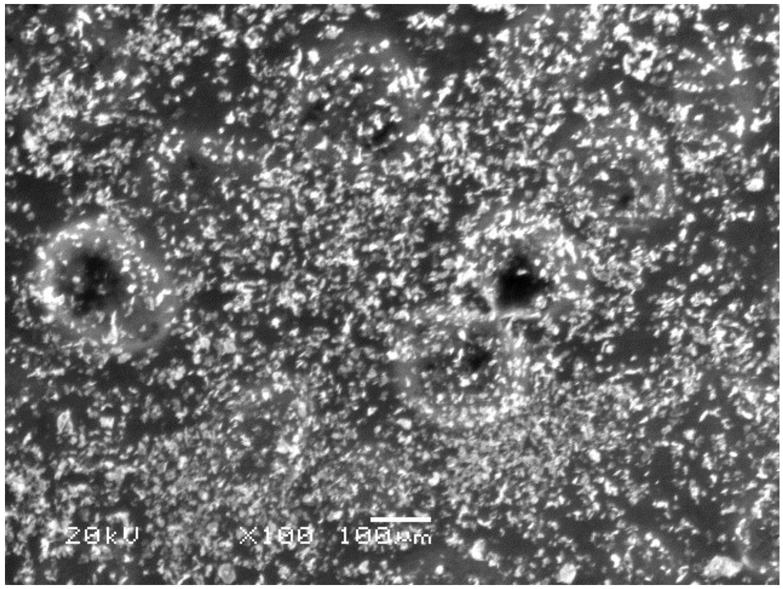


Figure 5.5: SEM MoS2 X100

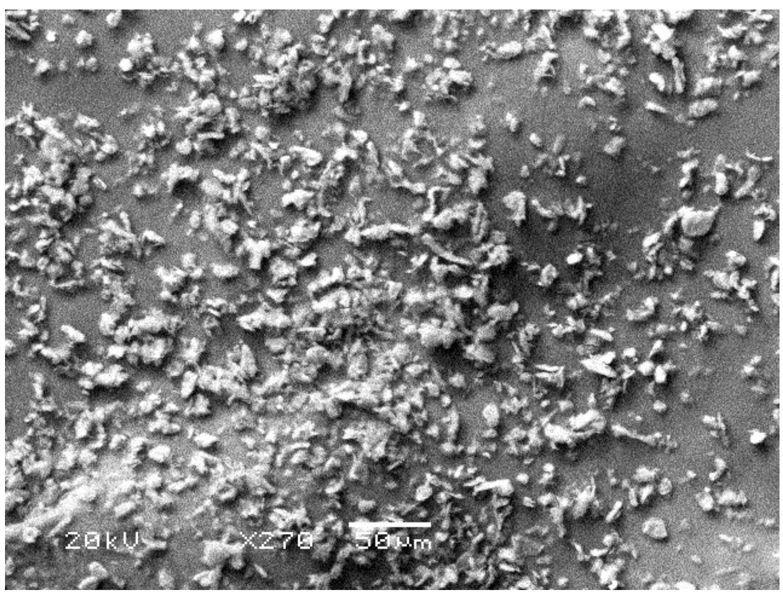


Figure 5.6: SEM MoS2 X270

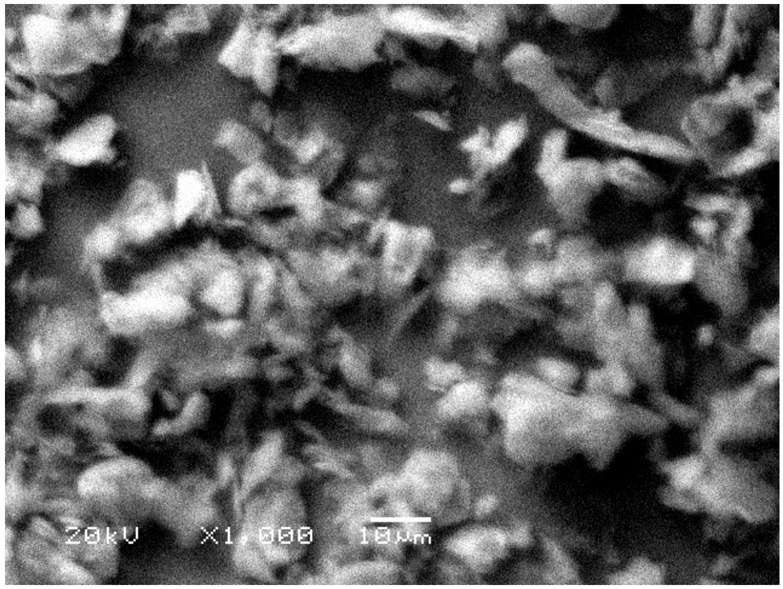


Figure 5.7: SEM MoS2 X1000

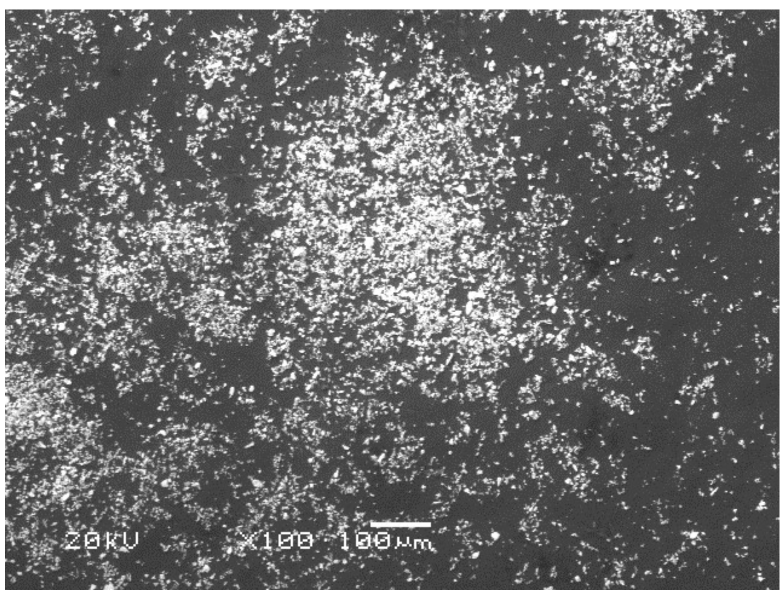


Figure 5.8: SEM Graphite X100

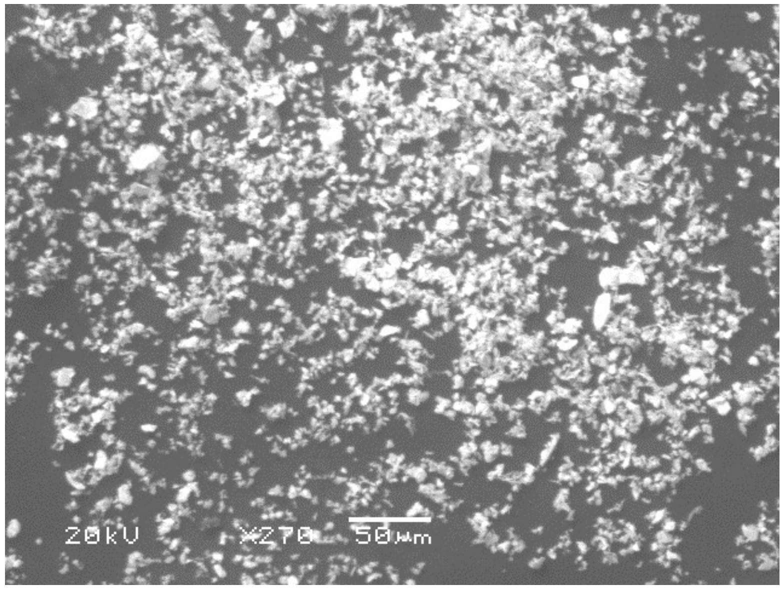


Figure 5.9: SEM Graphite X270

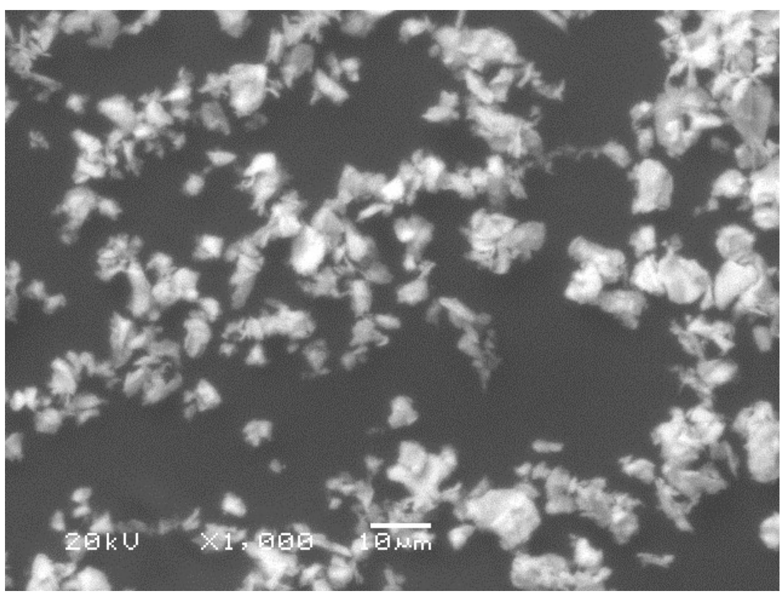


Figure 5.10: SEM Graphite X1000

From SEM analysis it is clear that calcium difluoride has much bigger particle size in comparison to other two lubricants. Hence for further experimental procedure molybdenum disulfide and graphite will be used as the solid lubricant. For MQL molybdenum disulfide and SAE40 mixture will be used as cutting fluid. Material properties of solid lubricant and SAE40 oil are listed in table.

Table 5.1: SAE40 Oil Properties

Specification	Value
Viscosity index	97
Pour point	-20
Flash point	210 °c
Physical state	Green liquid
Odor	Mild
Vapor density	>2.0
Relative density	15/4 °c: 0.865
Partition coefficient	>3.5

Table 5.2: MoS2 properties

Chemical formula	MoS2
Molar mass	$160.07 g/mol^{-1}$
Appearance	Black/lead-gray solid
Density	$5.06 g/cm^3$
Melting point	185 °C [2165 °F 158 K] decomposes
Solubility in water	Insoluble
Solubility	Decomposed by hot sulfuric acid, nitric acid, insoluble in dilute acids
Band gap	1.23 eV (2H)

Table 5.3: MoS2 properties

Chemical formula	C
Molar mass	$12.0107 g/mol^{-1}$
Appearance	Silver-gray to black
Density	2.09–$2.23 g/cm^3$
Melting point	---
Solubility in water	Insoluble
Solubility	Not Soluble in its pure form
Band gap	-0.01 eV

Heterogeneous mixture of SAE 40 and solid lubricant is used as cutting fluid for machining. Mixture can be formed by different weight ratios of solid lubricant and SAE 40 oil. Many researches had worked to find proper weight ratio of solid lubricant in heterogeneous mixture for better surface finish and less temperature generation. Krishnaa and Rao[19] used 5%, 10%, 15%, 20%, 30%, and 40% solid lubricant by weight with SAE 40 oil for testing cutting fluids lubricating and cooling properties, it was found that increasing the solid lubricant content in mixture improves machining process, 15% by weight of solid lubricant used in mixture gives the most optimum results.

Chapter 6

Experimental Setup

6.1 Experiment Details

Experiment has to be performed to obtain optimal process parameter for machining of AISI 4140 steel with CNMG120404 carbide tool of TN200 grade. As it is known AISI 4140 alloy steel is hard to machine by conventional method. Experiment will conducted for three different solid lubricant keeping same experiment parameters and response obtained will be compared to get best solid lubricant for the operation. Solid lubricants used for experiments will be Molybdenum disulfide, graphite and MQL (minimum quantity lubricant), for each lubrication method experiment will be conducted separately. For experiment three cutting parameter with three levels will be used. Three cutting parameters will be cutting speed, depth of cut and feed rate. Experiment will be conducted on heavy duty lathe machine KIRLOSAKR TURNMASTER 35. Heavy duty lathe machine has fixed level of cutting speeds. As cutting speed is required as cutting parameter, diameter of the workpiece will be varied to obtain desired cutting speed. While cutting the raw material to desired dimension value of responses will be observed, so that understanding of machining parameters will be more precised for machining of AISI 4140. Workpiece specification for initial cutting will be 50 mm in diameter and 1000 mm in length. Values of feed, and depth of cut will be same whereas value of cutting speed will be fixed according to the required diameter of the workpiece for final experiment. Lathe machine specifications are as give in table

Table 6.1: Machine Specification

Lathe machine	KIRLOSKAR TURNMASTER 35
Motor capacity	2.2 KW
Volts	415 V
Cutting tool	Tungsten carbide
Motor Speed	1430 rpm
Spindle speed	8/45-1120 rpm
Longitudinal speed	0.045-0.63 mm/rev

6.2 Process Parameter

For experimentation work three cutting parameters with three different levels are selected. Depth of cut, feed rate and cutting speed are the three cutting parameters which has most influence on the response. Experiments will be performed on the KIRLOSKAR TURNMASTER 35 lathe machine. From the available values of feed rates 0.2, 0.355 and 0.5 mm are selected for experiment work. Higher value of feed rate are selected to check its influence on response, when there is need of higher production rate. Values of depth of cut selected for experiments are 0.5, 0.75 and 1mm. Higher depth of cut value is selected to check the influence of parameter on reaction forces produced and power consumption. For selected workpiece material and available raw material dimensions, values of cutting speeds levels as 85, 125 and 190 m/min are selected. Available spindle speed on the selected lathe machine in working range are 450, 710 and 1120 RPM. So from available parameters raw material has to be turned in desired diameter. Selected parameters and there levels are shown in the table.

Table 6.2: Process Parameter and There Levels

Process Parameter	Level 1	Level 2	Level 3
Depth Of cut	0.5	0.75	1
Cutting Speed	85	125	190
Feed	0.2	0.355	0.5

For obtaining the desired cutting speed from available spindle speed it is required to calculate the diameter. Available dimension of raw material (AISI 4140) is 50mm dia and 1000mm in length. From available relation between spindle speed (RPM), Cutting speed (m/min) and diameter (mm). Calculated values of diameter are as shown in table.

Table 6.3: Diameter Values

Cutting Speed	Spindle Speed	Diameter
85	450	60
125	710	56
190	1120	54

Above combination of cutting speed and spindle speed are selected in such manner that value of diameter does not exceed more than 50mm. For final experiment values of diameter required are 44.7, 42.5 and 49.6mm. If it is required to perform experiment for 100 m/min cutting speed then machine will be set at 710 RPM and workpiece with 44.7 mm diameter will be used. While turning the raw material from 50 mm diameter to desired diameter data for two more different cutting speeds can be collected, so behavior of machining can be predicted more accurately.

Table 6.4: Cutting speed for initial cutting

Diameter	Spindle Speed	Cutting speed
50	710	176.33
50	1120	111.78

So readings for cutting speed 176.33 and 111.78 can be observed for more precised output from the experiment.

6.3 Design of experiment

As it is required to conduct experiment for turning operation by varying three cutting parameters at three different levels. Number of trials will be very high, so to optimize number of trials covering all different cutting parameters it is preferred to use Response surface methodology (Optimal 3x3), where 3 indicates number of levels and 3 indicates number of factors. Design of experiment was done using DESIGN EXPERT 10 software. Using Response surface methodology (optimal 3x3) 10 optimized trials were obtained, which covers all possible combination of cutting parameters to calculate influence of process parameters on responses. Results obtained by the experiment will be analyzed by ANOVA using DESIGN EXPERT 10 software. Trials obtained will be used for each solid lubricant separately, so it is required to perform 27 trials to complete experimental part. Using DESIGN EXPERT 10 analytical formula for calculating surface roughness and temperature will be developed.

Table 6.5: Trials by Surface response methodology

Std. No	Sr. No	F	D	Ø	N	V
5	1	0.355	1	54	1120	190
4	2	0.2	0.75	60	450	85
8	3	0.355	0.5	60	450	85
2	4	0.355	0.75	56	710	125
6	5	0.5	0.5	56	710	125
7	6	0.2	1	56	710	125
1	7	0.2	0.5	54	1120	190
3	8	0.5	1	60	450	85
9	9	0.5	0.75	54	1120	190
10	10	0.5	1	54	1120	190

Where C is Cutting Speed, N is Spindle Speed, D is Depth of cut, F is Feed

6.4 Temperature Measurement

There are different ways to quantify the cutting temperature like thermocouple, embedded thermocouples, infrared camera, radiation pyrometers, thermal imagining camera, temperature sensitive paints and indirect calorimetric technique. Heat generated during the machining operation can be measured by two type of techniques, either by conduction or by radiation techniques. Different devices work on different type of techniques, classification can be seen in figure.

Thermocouples have been a mainstream transducer utilized as a part of temperature estimation. Thermocouples are exceptionally tough and economical and can work over a wide temperature range. A thermocouple is made at whatever point two distinguished metals touch and the contact point delivers a little open circuit voltage as a function of temperature. On the off chance that these two distinguished material are the cutting tool and the workpiece material, then the thermocouple is known as a tool-chip or tool-work thermocouple the tool-work thermocouples strategy is utilized to quantify the cutting temperatures at the interface between the tool and chip. This procedure is quite simple to apply and it measures the mean temperature over the whole contact zone, hence for temperature measurement tool-work thermocouple will be used.

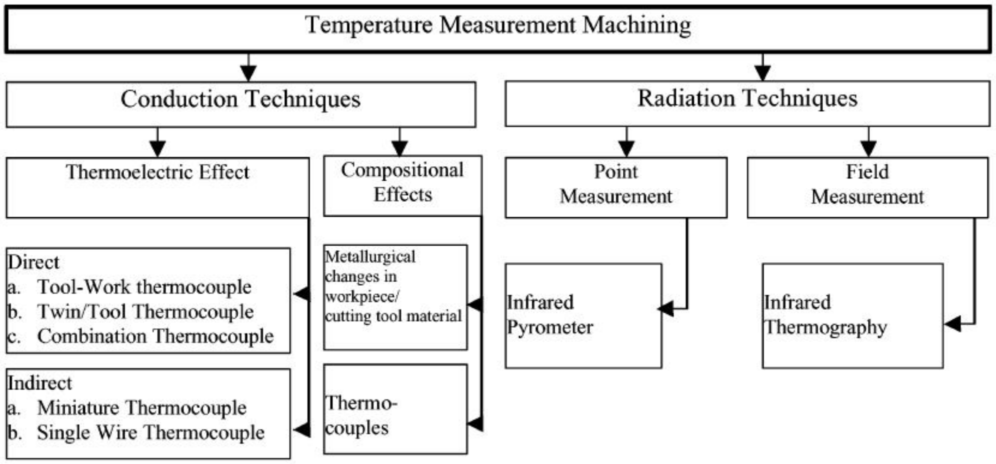


Figure 6.1: Temperature measurement techniques

6.4.1 Thermocuple Arrangement

Thermocouples comprise of two metal alloys consolidated toward one side and open at the other side. The emf signal at the open end is an function of the temperature at the closed end. As the temperature rises, the emf value goes up. The open-end signal is not just a component of closed end temperature (the point of estimation) additionally the temperature at the open end. Just by holding open end temperature at a standard temperature the obtained signal can be viewed as an direct function of the change in closed end temperature. The industrial standard for open end temperature is 0°C. Most tables and outlines make the presumption that open end temperature is at the 0°C level. Thermocouple works on the principle of seedback effect which is "phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances" as to obtain exact temperature reading it is very important to maintain the temperature at one of the end, so that it is possible to generate the relation between emf produced and temperature at unknown end of the thermocouple.

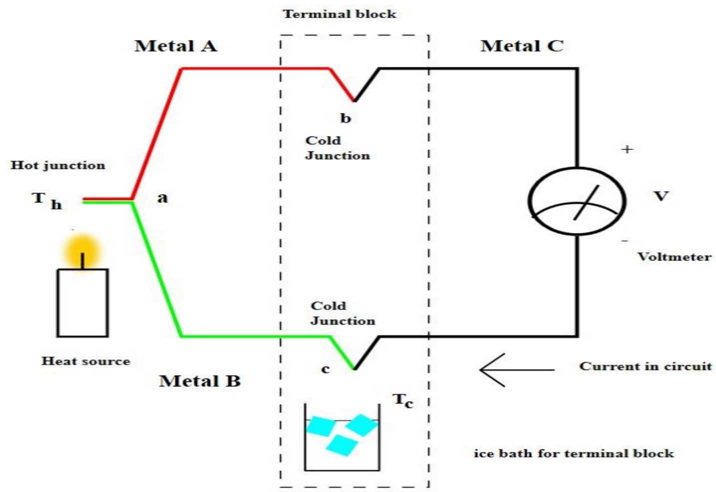


Figure 6.2: Working principle of thermocouple

Practically it is not possible to measure temperature at tool tip using conventional methods. Nose radius of tool tip ranges from 0.2mm to 1mm where as conventional thermocouple are bigger in size. It is possible to implant thermocouple in the tool by making a hole in it, But it changes the tool properties as well as temperature at exact tool tip cannot be determined. Preferred alternative to this problem are tool-work thermocouples for which Similar arrangement has to be made on lathe machine to calculate the temperature at tool chip interface. Such thermocouple are called hot-cold junction tool-work thermocouple. In Tool-Work thermocouples two dissimilar metals are workpiece and tool. During machining at the interface of tool tip and workpiece closed end or hot junction is formed. To reduce the emf loss we have to insulate the workpiece and tool from the lathe machine. Cold junction arrangement is required to obtain the precised temperature reading. To maintain cold junction at constant temperature it is required to insulate the junction, for insulation mercury bath is used. Disc of workpiece material is dipped in mercury bath which is connected to workpiece as shown in figure.

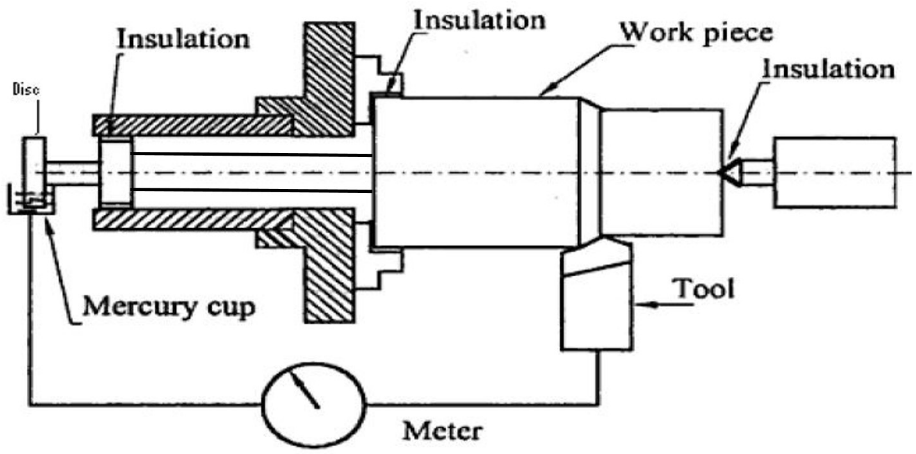


Figure 6.3: Tool-Work Thermocouple arrangement on lathe Machine[17]

Insulation of the workpiece from the lathe machine is done using glass wool. Whereas the arrangement for the mercury bath is manufactured and attached to the lathe machine. Open end of the thermocouple is made by connecting tool and cold junction by the means of copper wire, Emf values are obtained by connecting multi-meter at open end. It is very important to maintain the connectivity in thermocouple loop to obtain proper emf readings. A well insulated rod of AISI 4140 (Workpiece material) was placed in the spindle of the lathe machine, one end of the rod was connected to the workpiece and other end was connected to the disc immersed in the mercury bath. Cold junction setup was manufactured to hold mercury and rotating disc as well as to provide connectivity between copper wire and rotating disc.

6.4.2 Cold Junction

Temperature readings obtained in hot-cold junction tool-work thermocouple depends on the temperature difference between two junctions. It is very important to maintain the temperature of cold junction at steady state so that temperature at hot junction can be calculated more accurately. Insulation of cold junction is done by mercury bath. Cold junction is formed by connecting copper wires to the workpiece material.

To achieve both target, connecting copper wire to workpiece material and insulating the connection with mercury bath arrangement was made as shown in the figure.

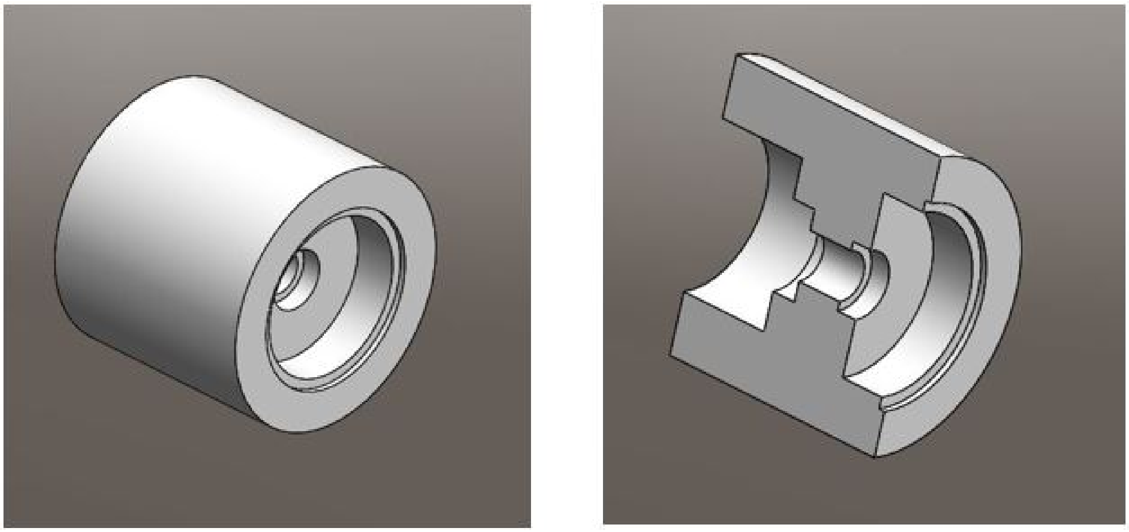


Figure 6.4: Mercury holder

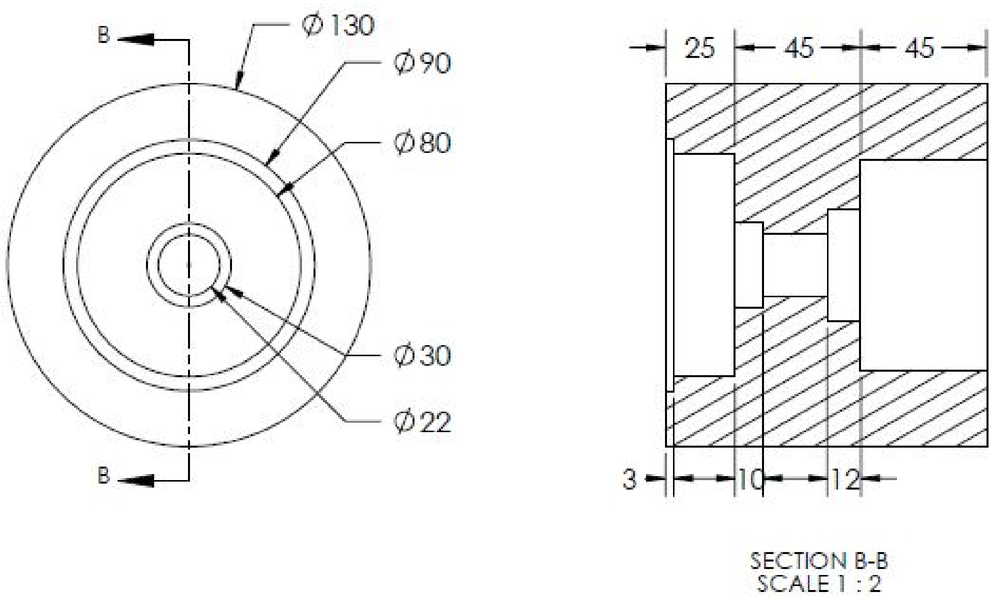


Figure 6.5: Mercury holder 2D (Dimensions)

Mercury holder is designed in such a way that it should hold mercury at high speed of the disc and it should be leak proof. Above shown figures demonstrate the 2D and 3D model of the mercury holder. One end of the holder is kept transparent so that the rotating disc can be visualized. One end of the holder is supported by the bearing to avoid vibration at high speed as well as bearings help to maintain the stability of the cold junction on the rod. A cadd model assembly was made to ensure the proper manufacturing of the cold junction setup.

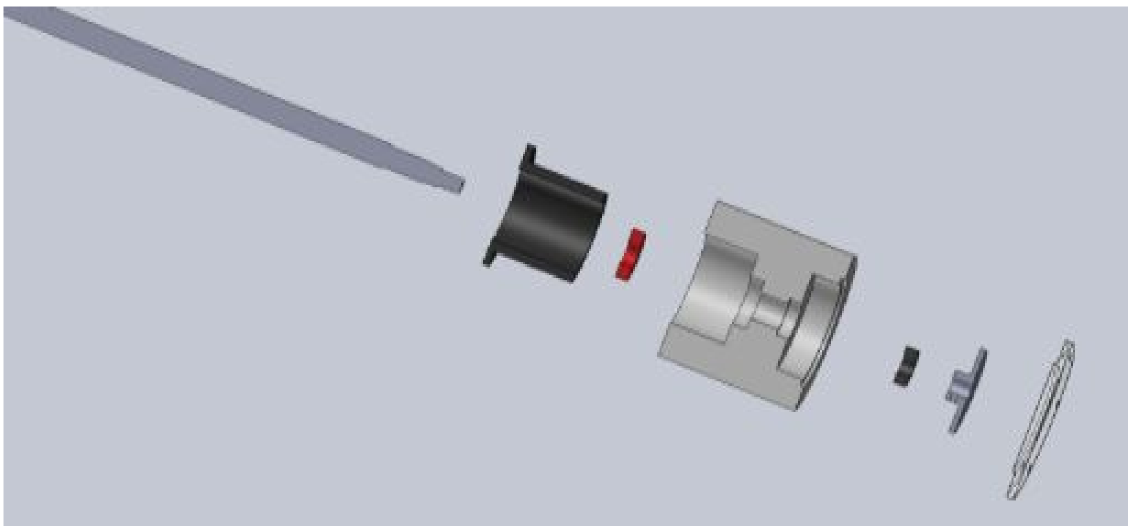


Figure 6.6: Assembly model of cold junction

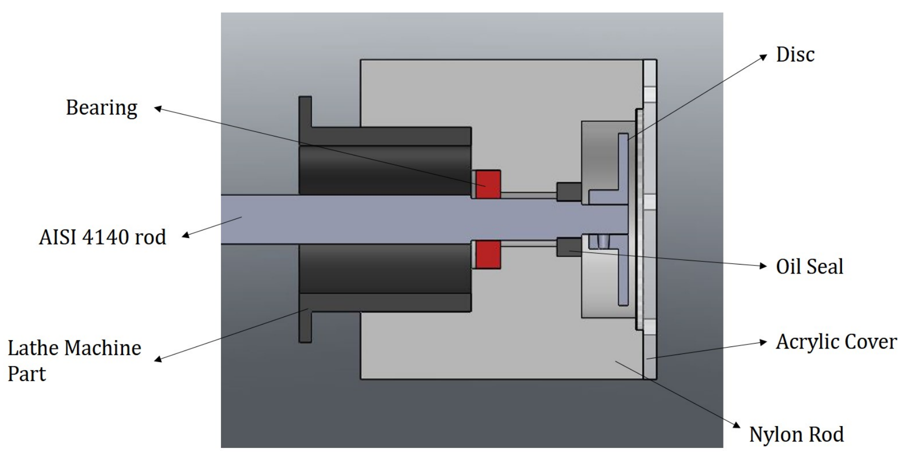


Figure 6.7: Cold junction assembly

Body of the cold junction assembly is made from nylon rod of dimension Ø130 mm x 300 mm. Oil seal is used to prevent leakage of mercury, oil seal is supported by rod from its inner side (rotating part of the seal) and outer part of seal is attached to the nylon rod by the means of adhesive. To reduce any chances of damage to the cold junction assembly, bearing is attached at other end. Bearing arrangement is made in such a way that it helps to constrain transitional motion of assembly as well as to reduce the vibration at higher spindle speed. Complete cold junction assembly is manufactured according to the proposed model dimensions. Assembly is attached to the lathe machine, for insulation of workpiece glass wool and plastic sheets are used according to the need. Arrangement of cold junction attached to the lathe machine is as shown in below images.

Figure 6.8: Cold junction arrangement

Figure 6.9: Cold junction arrangement

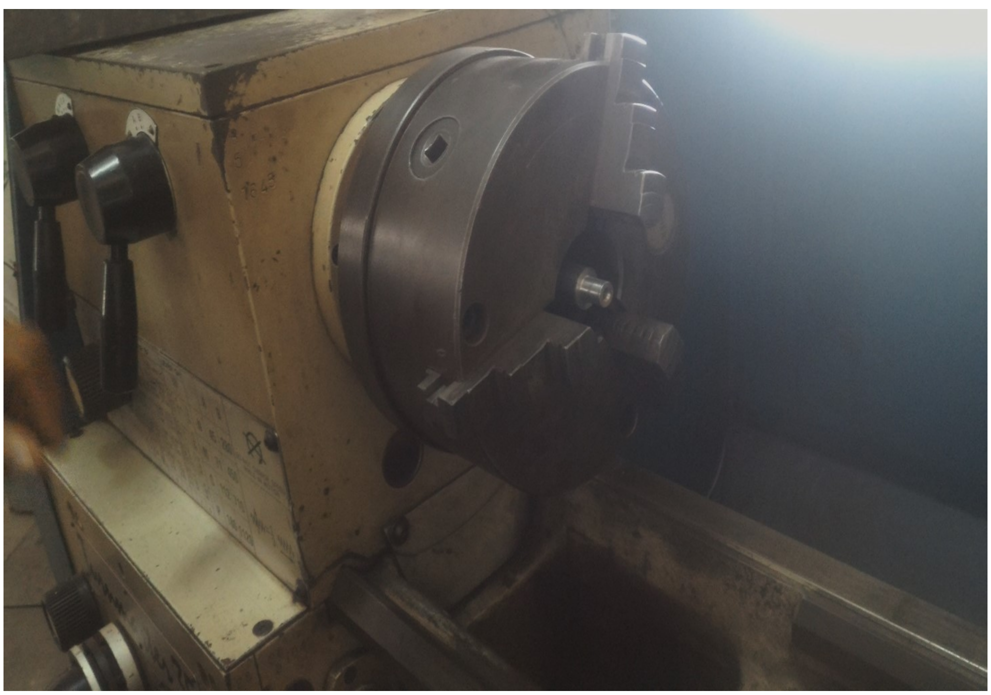


Figure 6.10: Cold junction arrangement

Insulation of rod from the spindle was done by nylon rod, bushes of nylon rod were inserted between the hollow spindle and AISI 4140 rod so that eccentricity of rod and spindle does not get disturbed during machining process. For top cover of cold junction acrylic sheet of thickness 13 mm was used, to make it leak proof silicon adhesive was used.

Hot-cold junction tool-work thermocouple arrangement was assembled on lathe machine, reference temperature (cold junction) is room temperature whereas two dissimilar metals are tungsten carbide and AISI 4140. It is important to obtain relation between emf and temperature for the given arrangement of the thermocouple.

6.4.3 Thermocouple calibration

There are many methods specified for calibrating the tool-work thermocouple. Furnace calibration, calibration by the means of lead bath for the hot junction and calibration of tool-work thermocouple by means of external flames of known temperature[18]. In present work work tool-work thermocouple calibration by the means of furnace kept at known temperature are used. Continuous chip obtained by the machining of workpiece material and tungsten carbide rod are used to form the hot junction. Hot junction of thermocouple was inserted in a metal plate with k type calibrated thermocouple. Metal plate attached with k type thermocouple and hot junction of tool-work thermocouple was kept in a furnace, temperature reading were obtained by K type thermocouple corresponding to emf generated by tool-work thermocouple.

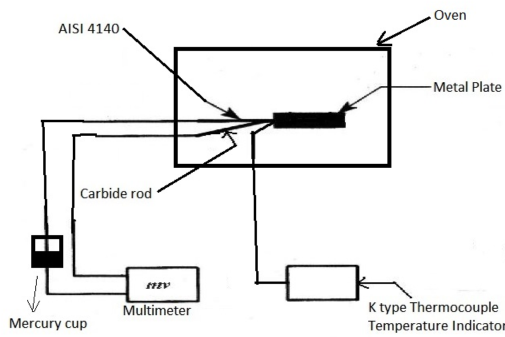


Figure 6.11: Thermocouple calibration

To obtain more precised value of thermoelectric relation for thermocouple many temperature readings were observed. Emf generated by the hot junction formed by the carbide rod and AISI 4140 chip were recorded using multimeter whereas simultaneously temperature readings were obtained by K type thermocouple using a temperature indicator. Thermoelectric relationship for tool-work thermocouple was obtained using Graphpad prism from the available readings. Data logger of K type thermocouple was set to obtain temperature of metal plate after every 4 seconds, total 1660 temperature readings were taken by thermocouple.

Figure 6.12: Calibration setup

Figure 6.13: Calibration setup

Calibration by the means of furnace has some limitations, we can obtain linearly increasing temperature with steady state condition but we cannot go for higher values of temperature. To avoid emf leakage workpiece metal chip and copper wires were insulated by glass fiber tape. For higher readings of temperature metal plate was heated by Oxy-acytelene flames for obtaining higher temperatures. For each value of emf average value of temperature were taken and given an input to the Graphpad for obtaining the theroelectric relationship.

Table 6.6: Calibration Readings

EMF	T	EMF	T	EMF	T	EMF	T	EMF	T
0.1	45.112	1.3	128.709	2.5	213.076	3.7	295.642	9.6	734.358
0.2	52.577	1.4	136.332	2.6	221.248	3.8	302.504	10.0	745.985
0.3	59.632	1.5	144.021	2.7	227.863	3.9	311.116	10.4	760.431
0.4	66.602	1.6	151.007	2.8	234.200	4	317.829	11.0	791.687
0.5	73.607	1.7	158.000	2.9	241.406	4.1	324.339	11.5	845.012
0.6	80.931	1.8	165.508	3	247.577	4.2	335.138	12.2	909.712
0.7	87.976	1.9	172.376	3.1	253.434	5.6	421.354	12.9	960.098
0.8	95.646	2	177.339	3.2	261.455	5.9	440.157		
0.9	102.246	2.1	184.942	3.3	267.278	6.8	507.896		
1.0	108.582	2.2	192.413	3.4	274.457	7.5	570.186		
1.1	113.382	2.3	198.921	3.5	281.991	8.4	651.846		
1.2	122.104	2.4	204.970	3.6	288.704	9.3	706.378		

It was found that emf and temperature are linearly dependent. A multiple correlation coefficient of 0.9998 was obtained from graphpad. Equation obtained from graphpad was $Temperature = 70.81\text{x}EMF + 36.29$

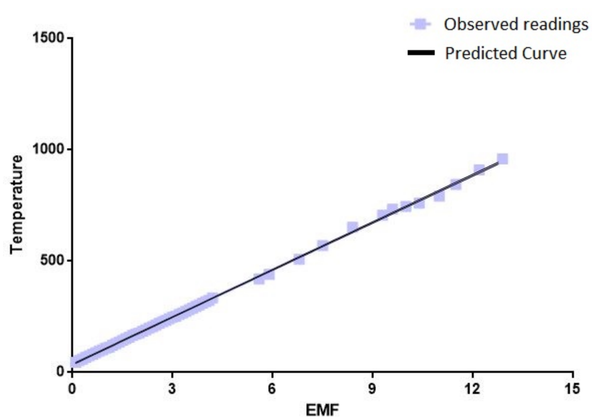


Figure 6.14: Calibration Curve

Chapter 7

Experimental Results

Experiment were performed for selected process parameters, for each solid lubricant and dry cutting separate set of trials were performed. Three levels for three parameters were selected, using ANOVA process parameters were set for the trial as mentioned in earlier chapters. Each experiment contain nine trial which were sufficient to get the influence of parameters on the machining. Available raw material was of 60 mm dia, for each set of experiment three pieces of 54 mm dia, three pieces of 56 mm dia and three pieces of 60 mm dia are required. For all experiments to be performed total of 18 workpieces has to be machined, nine workpieces to 54 mm dia and nine workpieces to 56 mm dia. Experimental readings were taken for machining this 18 workpieces so that we can observe effect of process parameter more precisely. Three different level of process parameter were selected for this experiments.

Table 7.1: Process Parameter for raw material

Process Parameter	D	F	V (Dia 54)	V (Dia 56)
Level 1	0.25	0.2	123	127
Level 2	0.5	0.355	194	201
Level 3	0.75	0.5		

Using this set of trials we can predict the influence of depth of cut and feed on the temperature generated at tool chip interaction and surface finish of the product formed. All eighteen trials were performed in dry cutting condition. For each set of trials different tool was used so that the tool wear should not have any influence on the observed readings. Using L9 Surface response methodology different process parameter for trials were obtained as mentioned in above chapters. Experiment were conducted in three different environment. In two cases two different lubricants were used and in third case dry cutting conditions were employed. Using such environments we can easily compare the effect of lubricants on turning operation. Results obtained from the experiments are as mentioned below.

Table 7.2: Experimental reading for raw material (Ø56 mm)

Std. No	Sr. No	F	D	Ø	N	V	I.P	P	T	S.R
7	1	0.5	0.25	56.5	1120	201	35	110	723.147	8.911
9	2	0.355	0.75	57.5	1120	201	35	145	652.337	3.011
1	3	0.2	0.25	56.5	710	127	25	45	857.686	5.657
2	4	0.355	0.5	57	710	127	25	80	815.2	5.330
8	5	0.2	0.5	57	1120	201	35	85	801.038	2.895
4	6	0.355	0.25	56.5	1120	201	35	95	921.415	8.142
5	7	0.5	0.5	57	1120	201	35	135	900.172	5.727
6	8	0.2	0.75	57.5	1120	201	35	140	875.3885	2.942
3	9	0.5	0.75	57.5	710	127	25	130	868.3075	8.460

Table 7.3: Experimental reading for raw material (Ø54 mm)

Std. No	Sr. No	F	D	Ø	N	V	I.P	P	T	S.R
7	1	0.5	0.25	54.5	1120	194	35	110	659.418	6.055
9	2	0.355	0.75	55.5	1120	194	35	145	567.365	2.985
1	3	0.2	0.25	54.5	710	123	25	45	546.122	8.200
2	4	0.355	0.5	55	710	123	25	80	542.5815	6.060
8	5	0.2	0.5	55	1120	194	35	85	531.96	3.076
4	6	0.355	0.25	54.5	1120	194	35	95	680.661	8.016
5	7	0.5	0.5	55	1120	194	35	135	595.689	8.279
6	8	0.2	0.75	55.5	1120	194	35	140	574.446	2.856
3	9	0.5	0.75	55.5	710	123	25	130	560.284	5.428

Table 7.4: Experimental readings for dry cutting

Std. No	Sr. No	F	D	Ø	N	V	I.P	P	T	S.R
5	1	0.355	1	54	1120	190	35	150	716.066	8.258
4	2	0.2	0.75	60	450	85	20	50	666.499	2.854
8	3	0.355	0.5	60	450	85	20	100	680.661	6.534
2	4	0.355	0.75	56	710	125	25	55	581.527	6.809
6	5	0.5	0.5	56	710	125	25	90	716.066	3.087
7	6	0.2	1	56	710	125	25	160	730.228	5.765
1	7	0.2	0.5	54	1120	190	35	90	602.77	8.337
3	8	0.5	1	60	450	85	20	95	659.418	3.161
9	9	0.5	0.75	54	1120	190	35	100	708.985	8.420
10	10	0.5	1	54	1120	190	35	155	746.258	8.624

Table 7.5: Experimental readings with Graphite

Std. No	Sr. No	F	D	Ø	N	V	I.P	P	T	S.R
5	1	0.355	1	54	1120	190	35	150	701.824	7.797
4	2	0.2	0.75	60	450	85	20	50	616.852	2.716
8	3	0.355	0.5	60	450	85	20	80	659.338	5.174
2	4	0.355	0.75	56	710	125	25	60	574.366	6.478
6	5	0.5	0.5	56	710	125	25	90	680.581	2.851
7	6	0.2	1	56	710	125	25	110	694.743	5.219
1	7	0.2	0.5	54	1120	190	35	130	595.609	8.041
3	8	0.5	1	60	450	85	20	70	638.095	2.789
9	9	0.5	0.75	54	1120	190	35	100	673.5	8.056
10	10	0.5	1	54	1120	190	35	155	694.743	8.226

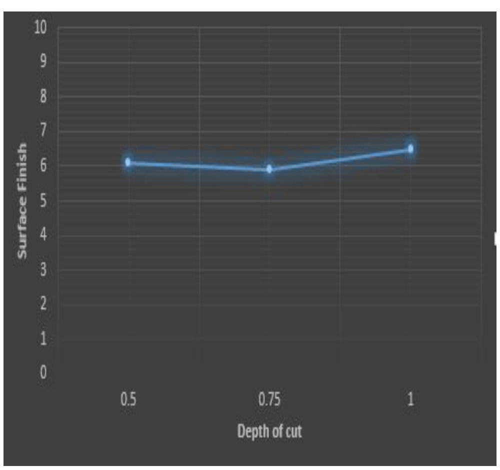
Table 7.6: Experimental readings with Molybdenum disulfide

Std. No	Sr. No	F	D	Ø	N	V	I.P	P	T	S.R
5	1	0.355	1	54	1120	190	35	150	652.337	7.299
4	2	0.2	0.75	60	450	85	20	50	602.77	2.314
8	3	0.355	0.5	60	450	85	20	80	638.175	4.622
2	4	0.355	0.75	56	710	125	25	60	531.96	5.174
6	5	0.5	0.5	56	710	125	25	90	659.418	2.563
7	6	0.2	1	56	710	125	25	110	680.661	5.165
1	7	0.2	0.5	54	1120	190	35	130	546.122	7.259
3	8	0.5	1	60	450	85	20	70	624.013	2.194
9	9	0.5	0.75	54	1120	190	35	100	645.256	7.237
10	10	0.5	1	54	1120	190	35	155	652.337	7.322

Effect of independent process parameter on turning operation were obtained from Design Expert 10. As temperature generated during the operation plays important role in the tool wear and surface finish is termed as an important output of the turning operation, temperature at tool chip interface and surface finish value were desired responses from the turning operation. Graphs for all individual process parameter against responses were plot. To evaluate which of the cutting environment is better graphs of all cutting conditions were compared.

7.1 Results for machining with no lubrication

Parameters affecting machining process were observed under three different experimental trials. As mentioned in earlier chapters, experimental readings were taken during machining of raw material also. Effect on temperature and surface finish by individual parameter as well as by combined effects of parameter were calculated using ANOVA. From observed readings, graph of each parameter against response was plotted. It was found that feed has the greatest influence on surface roughness of the workpiece. Influence of depth of cut and cutting speed is negligible as compared to feed.



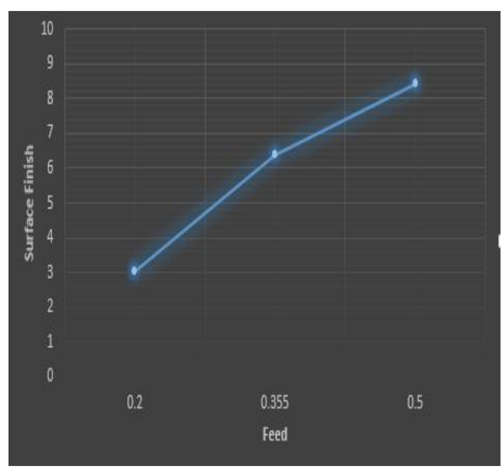


Figure 7.1: Depth of cut vs Surface roughness and Feed vs Surface roughness

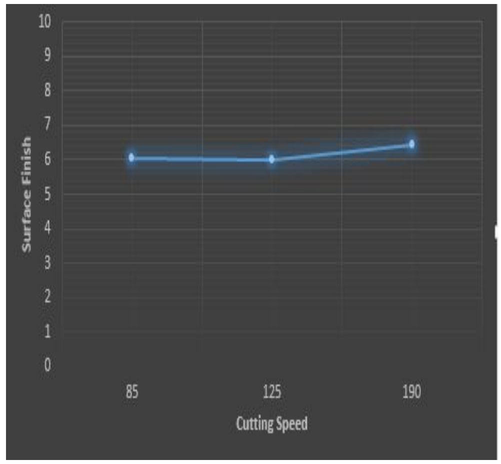


Figure 7.2: Cutting Speed vs Surface roughness

It is clear from the graphs that there is considerable change in the value of surface roughness with the change in value of feed. Where as value of surface roughness is almost constant for all values of depth of cut and cutting speed. With increase in value of feed value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal method, equation for surface roughness was generated.

$$
\begin{aligned}
S.R = &-1.71 + 29.853\text{x}F - 5.158\text{x}D + 0.03\text{x}V + 7.007\text{x}F\text{x}D - 24.487\text{x}F^2 \\
&+ 1.451\text{x}D^2 - 0.00012\text{x}V^2
\end{aligned}
$$

.Using the above equation value of surface roughness for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

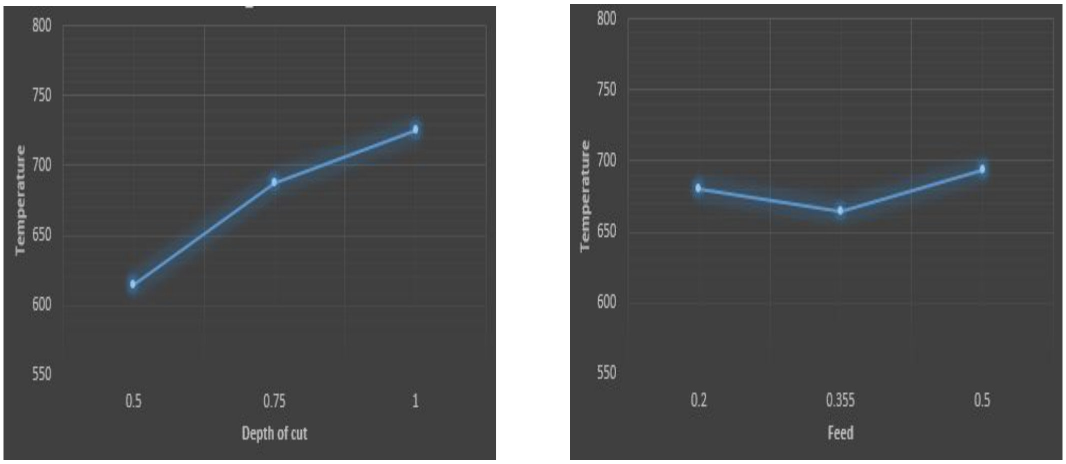


Figure 7.3: Depth of cut vs Temperature and Feed vs Temperature

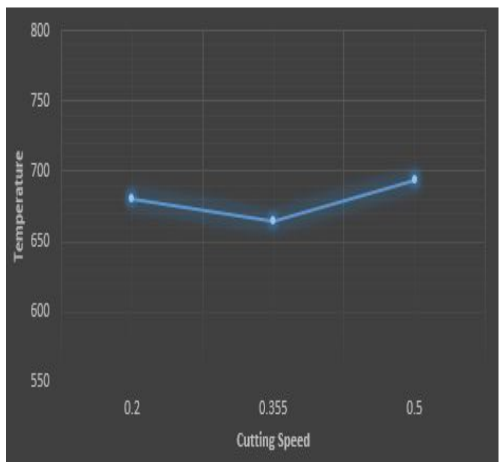


Figure 7.4: Cutting speed vs Temperature

It is clear from the graphs that there is considerable change in the value of temperature at tool-chip interface with the change in value of depth of cut. Where as value of temperature at tool-chip interface is almost constant for all values of feed and cutting speed. With increase in value of depth of cut value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal

method, equation for temperature at tool-chip interface was generated.

$$T = 332.709 - 182.042\text{x}F + 550.142\text{x}D + 1.029\text{x}V + 167.336\text{x}F\text{x}D + 1.575\text{x}F\text{x}V$$
$$- 1.47975\text{x}D\text{x}V - 224.801\text{x}F - 138.372\text{x}D^2$$

Using the above equation value of surface roughness for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

7.2 Result for machining with graphite

As mentioned in above section graphs for each parameter against the response values were plotted to evaluate there effect. Machining was done using graphite in SAE 40 oil 15% by weight as cutting fluid. For MQL solid lubricant mixture was used by the means of pressurized nozzle arrangement.

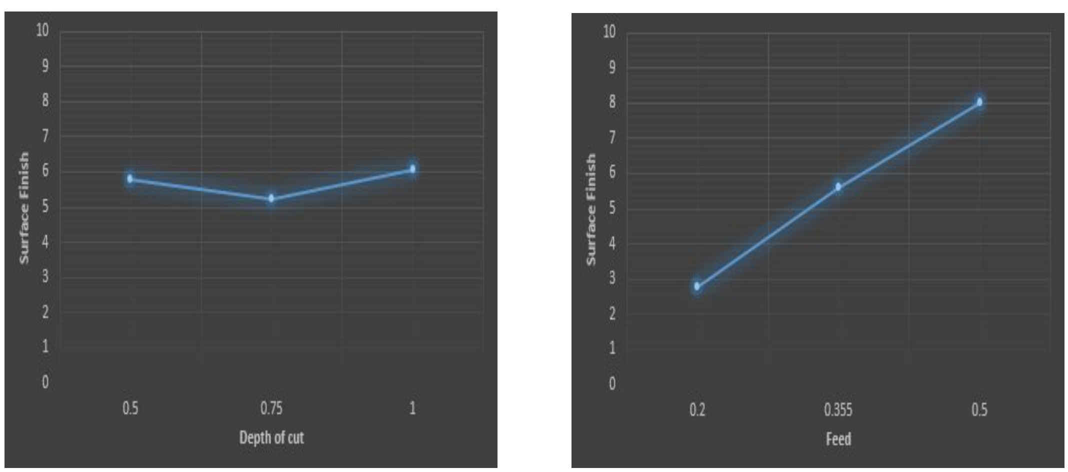


Figure 7.5: Depth of cut vs Surface roughness and Feed vs Surface roughness

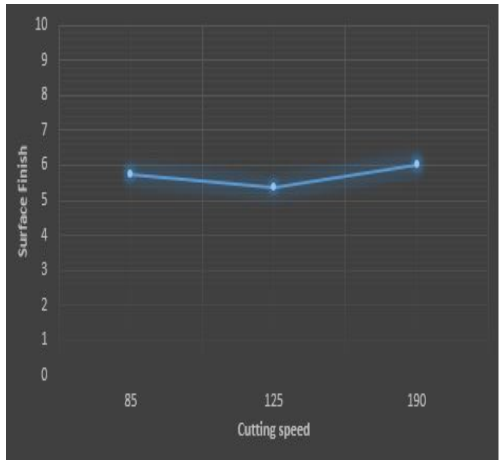


Figure 7.6: Cutting Speed vs Surface roughness

It is clear from the graphs that there is considerable change in the value of surface roughness with the change in value of feed. Where as value of surface roughness is almost constant for all values of depth of cut and cutting speed. With increase in value of feed value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal method, equation for surface roughness was generated.

$$S.R = 4.623 + 22.480\text{x}F - 9.402\text{x}D - 0.039\text{x}V - 2.0780\text{x}F\text{x}D - 4.705\text{x}F^2 + 6.375\text{x}D^2 0.00012\text{x}V^2$$

.Using the above equation value of surface roughness for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

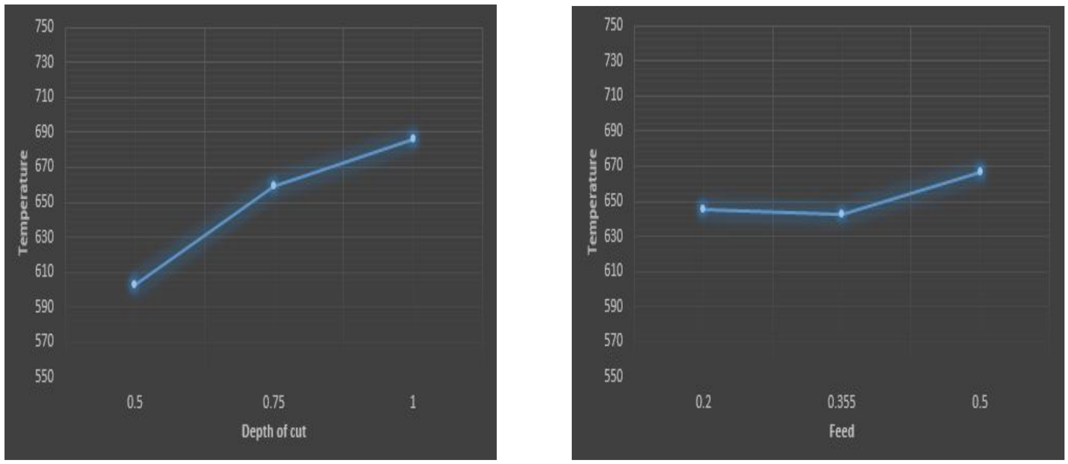


Figure 7.7: Depth of cut vs Temperature and Feed vs Temperature

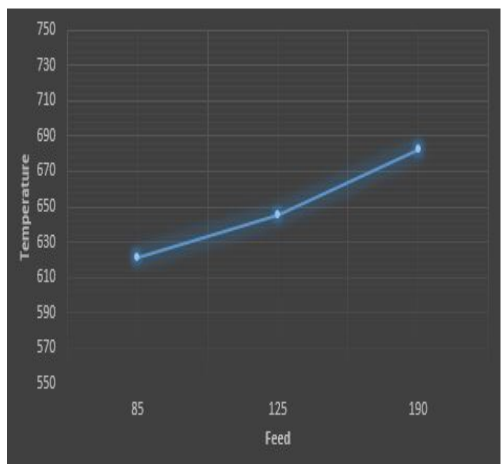


Figure 7.8: Cutting speed vs Temperature

It is clear from the graphs that there is considerable change in the value of temperature at tool-chip interface with the change in value of depth of cut. Where as value of temperature at tool-chip interface is almost constant for all values of feed and cutting speed. With increase in value of depth of cut value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal

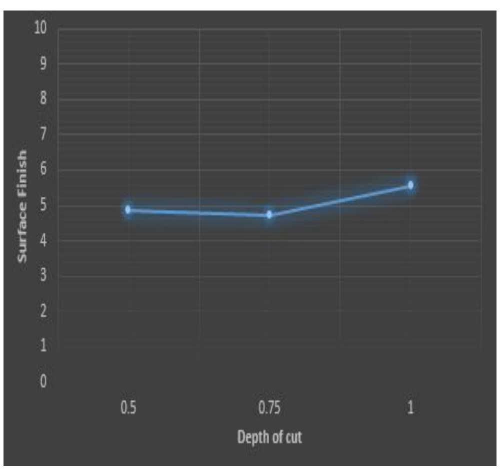
method, equation for temperature at tool-chip interface was generated.

$$T = 206.992 + 1050.799\text{x}F + 91.093\text{x}D + 2.073\text{x}V - 78.356\text{x}F\text{x}D + 5.968\text{x}F\text{x}V$$
$$- 4.844\text{x}D\text{x}V - 2451.010\text{x}F + 483.501\text{x}D^2$$

Using the above equation value of surface roughness for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

7.3 Result for machining with molybdenum disulfide

As mentioned in above section graphs for each parameter against the response values were plotted to evaluate there effect. Machining was done using molybdenum disulfide in SAE 40 oil 15% by weight as cutting fluid. For MQL solid lubricant mixture was used by the means of pressurized nozzle arrangement.



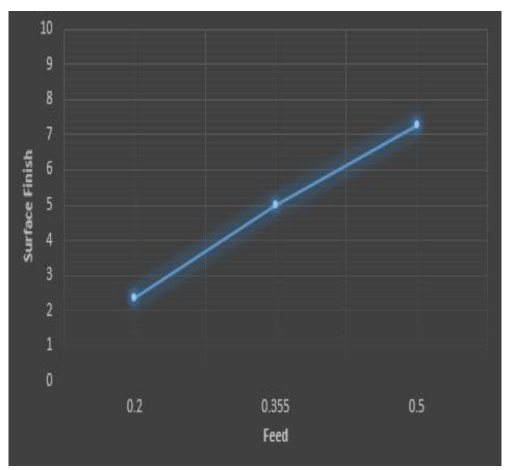


Figure 7.9: Depth of cut vs Surface roughness and Feed vs Surface roughness

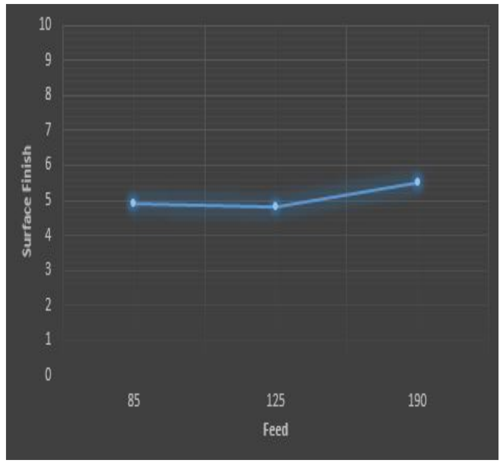


Figure 7.10: Cutting Speed vs Surface roughness

It is clear from the graphs that there is considerable change in the value of surface roughness with the change in value of feed. Where as value of surface roughness is almost constant for all values of depth of cut and cutting speed. With increase in value of feed value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal method, equation for surface roughness was generated.

$$S.R = 0.593 + 24.334\text{x}F - 1.965\text{x}D - 0.037\text{x}V - 7.012\text{x}F\text{x}D - 3.796\text{x}F^2$$
$$+ 3.127\text{x}D^2 0.00014\text{x}V^2$$

.Using the above equation value of surface roughness for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

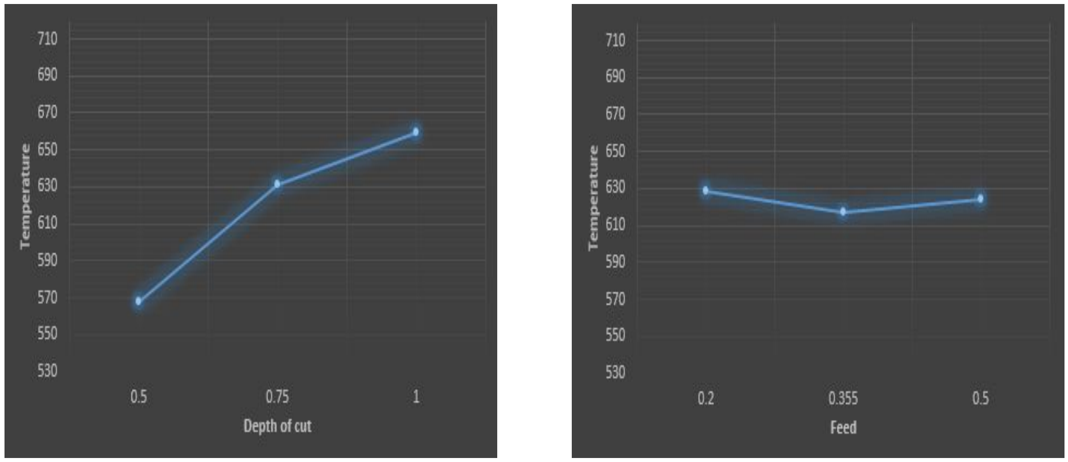


Figure 7.11: Depth of cut vs Temperature and Feed vs Temperature

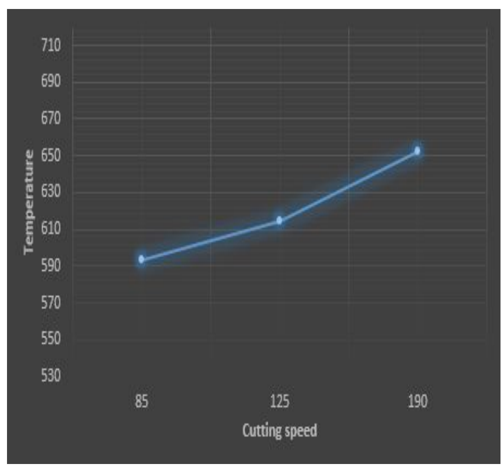


Figure 7.12: Cutting Speed vs Temperature

It is clear from the graphs that there is considerable change in the value of temperature at tool-chip interface with the change in value of depth of cut. Where as value of temperature at tool-chip interface is almost constant for all values of feed and cutting speed. With increase in value of depth of cut value of surface roughness increases almost linearly. Using ANOVA for surface response methodology by optimal

method, equation for temperature at tool-chip interface was generated.

$$T = -6.72072 + 652.673\text{x}F + 804.307\text{x}D + 2.015\text{x}V - 8.546\text{x}F\text{x}D + 0.368\text{x}F\text{x}V$$
$$- 2.114\text{x}D\text{x}V - 1042.033\text{x}F - 221.759\text{x}D^2$$

Using the above equation value of temperature for different values input parameters can be checked for dry cutting condition. For the given equation units of the input process parameters should be same as it is given during experiments. Value of surface roughness given by the equation is limited to the environmental conditions at the time of machining.

7.4 Comparison of cutting fluids

In present work we have used two different solid lubricants graphite and molybdenum disulfide. Using Design Expert 10 (ANOVA) from obtained results of experiments, equation for both responses (Tool-chip interface temperature and surface roughness) in all three environment were developed. Several random values of input process parameters were taken from low level to high level and graph for all three conditions were plotted.

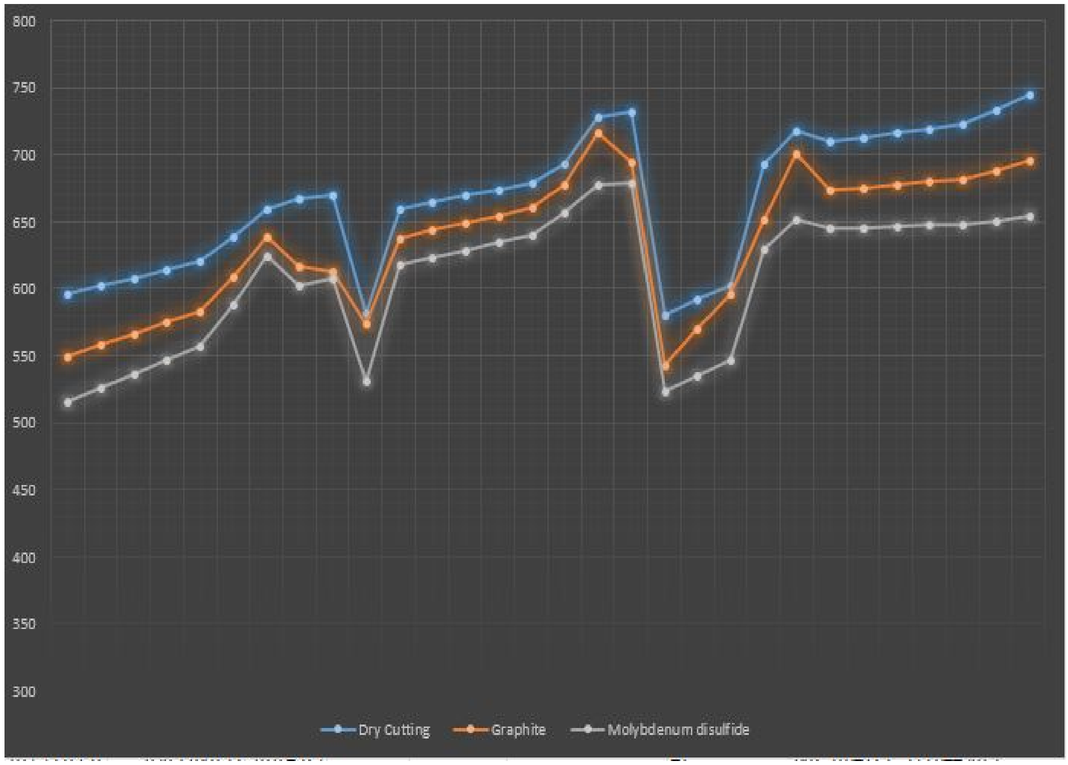


Figure 7.13: Temperature Values

From plots it can be observed that there is reduction in tool-chip interface temperature when solid lubricants are used. For all values of process parameter the temperature readings in case of solid lubricants is less as compared to dry cutting. Tool chip interface temperature in case of molybdenum disulfide is less as compared to graphite for all values of selected process parameters. It can be concluded that molybdenum disulfide in SAE 40 oil 15% by weight is better lubricant than graphite, it helps to keep tool chip interface temperature at lower value as compared to dry cutting and graphite.

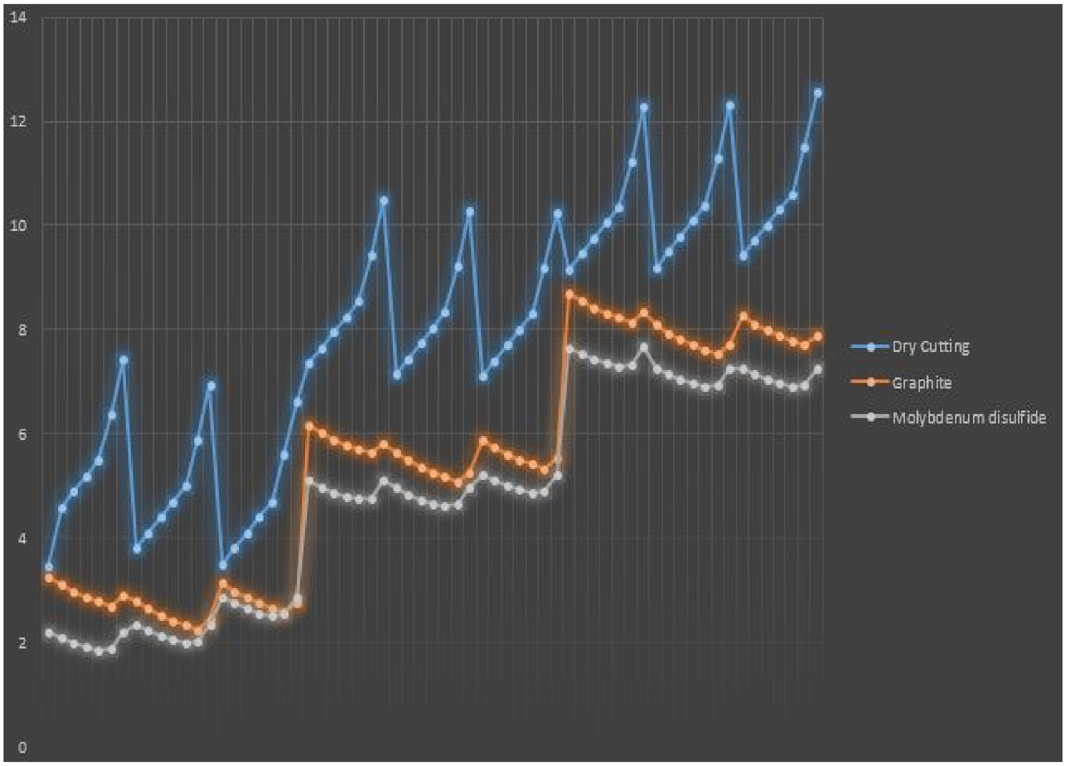


Figure 7.14: Surface Roughness Values

Surface finish obtained in machining process is measured in terms of surface roughness. For all selected process parameters plots shows that surface finish is poor in case of dry cutting as compared to ts surface finish obtained in case of solid lubrication. Molybdenum disulfide shows good characteristic for obtaining better surface finish on the workpiece. For all selected process parameters, surface finish is best in case of molybdenum disulfide as compared to graphite.

Chapter 8

Numerical Analysis

Mathematical model generated by experimental readings is adequate to give value of surface finish and temperature at tool-chip interface for machining of AISI 4140 with tungsten carbide tool of given specification. For the selected process parameter simulations were performed to obtain maximum temperature at tool-chip interface. Simulations were performed on ANSYS workbench 16.2. Tools end face of body was kept at room temperature whereas at the tool tip heat flow was given input. It was observed that temperature obtained by the mathematical models are within 5% range of the temperature readings obtained by the simulation.

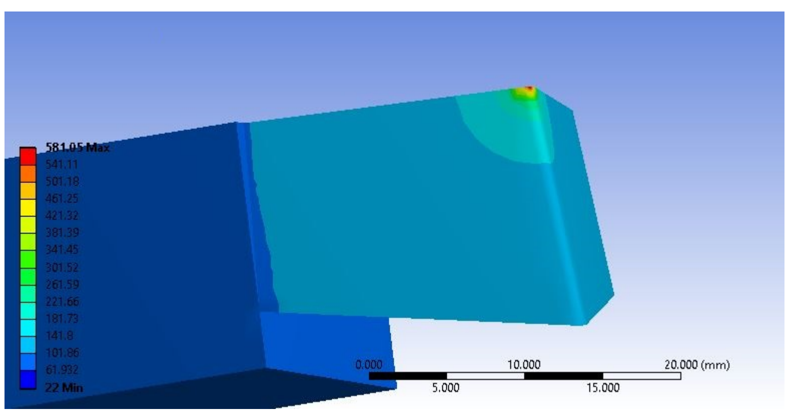


Figure 8.1: Temperature at tool tip

Above simulation was done for process parameter 0.355 as feed, 0.5 as depth of cut and 85 as cutting speed. Experimental value of tool tip temperature was 582.034. Value obtained from the simulation is 581.05 which is 0.169% error.

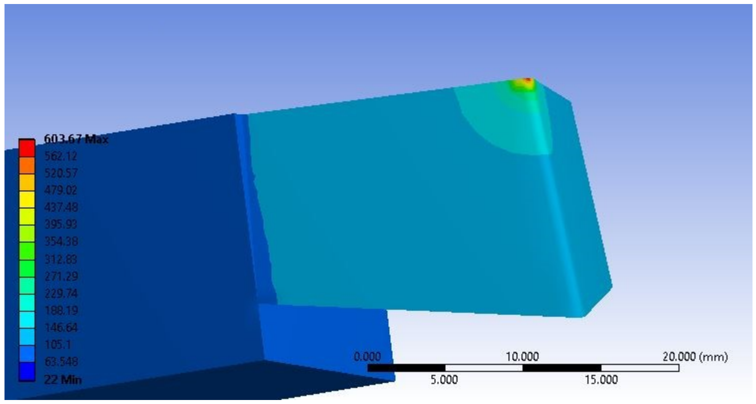


Figure 8.2: Temperature at tool tip

Above simulation was done for process parameter 0.5 as feed, 0.5 as depth of cut and 125 as cutting speed. Experimental value of tool tip temperature was 602.37. Value obtained from the simulation is 603.67 which is 0.216% error.

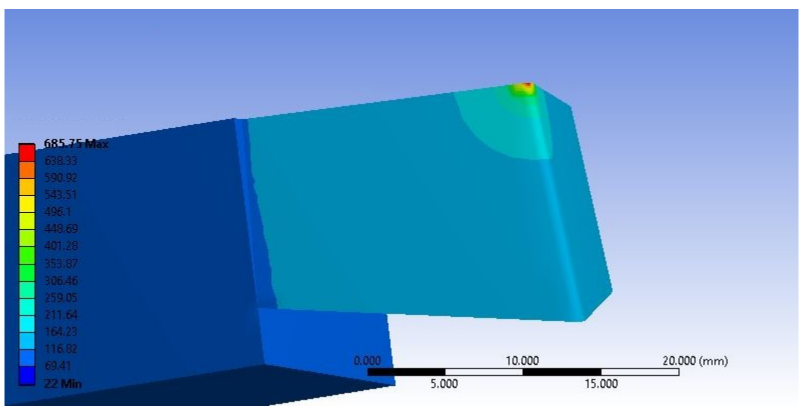


Figure 8.3: Temperature at tool tip

Above simulation was done for process parameter 0.355 as feed, 0.75 as depth of cut and 125 as cutting speed. Experimental value of tool tip temperature was 678.866. Value obtained from the simulation is 685.75 which is 1.01% error.

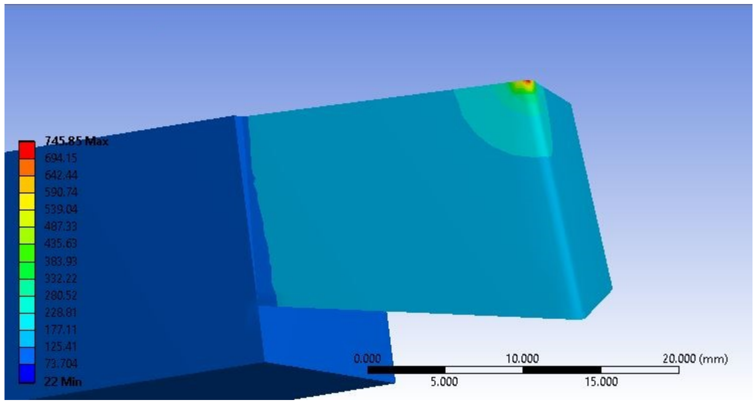


Figure 8.4: Temperature at tool tip

Above simulation was done for process parameter 0.355 as feed, 0.5 as depth of cut and 85 as cutting speed. Value obtained by mathematical for tool tip temperature was 744.896. Value obtained from the simulation is 745.85 which is 0.128% error.

Values obtained from the simulation and mathematical model are within 5% range of each other. Hence mathematical model generated can be used to calculate surface finish and temperature at tool-chip interface at any value of process parameters.

Chapter 9

Summary and conclusion

9.1 Summary

Solid lubrication (MQL) can be used to reduce tool-chip interface temperature and surface roughness of the workpiece. By reducing tool-chip interface temperature we can increase tools life and reduce machining time, as we can work with higher values of process parameter as well as it is possible to obtain better surface finish. With simple arrangements on lathe machine we can imply MQL methods using solid lubricants. Mathematical model was generated using ANOVA (Surface response methodology) for temperature generated at tool-chip interface and surface roughness of the workpiece for dry cutting condition and each lubricant separately. Validation of mathematical model was done by comparing the results of simulation done on ANSYS workbench 16.2.

9.2 Conclusion

In order to obtain temperature at tool-chip interface and surface roughness under different cutting condition experiment were conducted by varying process parameters of machining such as feed, depth of cut, cutting speed, lubricants. Simulations were done to validate the result obtained from experiment trials. From the results obtained it can be concluded that surface roughness produced during turning operation can be reduced by the use of MQL (solid lubricant). Molybdenum disulfide in SAE 40 oil 15% by weight is better lubricant that graphite in SAE 40 oil 15% by weight under all process parameters. Feed is the most influencing process parameter on surface roughness produced. By the use of MQL with solid lubricants temperature at tool-chip interface can be reduced. Molybdenum disulfide in SAE 40 oil 15% is best suited to reduce temperature as compared to graphite and other cutting fluids. Depth of cut is the most influencing process parameter for the temperature generation.

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