Comparative study of conventional and minimum quantity lubrication (MQL) during machining 17-4PH stainless steel

Bachelor of Technology
in

Mechanical Engineering
by

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May 2015

CERTIFICATE

This is to certify that the work in the thesis entitled "Comparative study of conventional and minimum quantity lubrication (MQL) during machining 17-4PH stainless steel" by Dinesh Prasad Hati, has been conducted under my supervision required for partial fulfilment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2014-2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

I am deeply indebted to **Dr. Soumya Gangopadhyay**, my advisor and guide, for the motivation, guidance and patience throughout the research work. I appreciate his broad range of expertise and attention to detail, as well as the constant encouragement he has given me over the years.

I am very thankful to **Mr Arabinda Khuntia,** technical staff of Mechanical engineering department who assisted me in conducting the tuning experiment. I also pay my gratitude to **Mr GangadharTalla,** research scholar for helping me with optimisation techniques to find the optimum result for my process parameters.

ABSTRACT

Machining of different material with the conventional water soluble cutting oils have some challenges because of poor machinability characteristics. Many technology have been developed but minimum quantity lubrication (MQL) is the most frequent as it has merits over conventional cooling. The current work is focused upon the benefits of MQL over conventional cooling. Here the process parameter were compared for the machining of 17-4PH stainless steel. It was observed that machining with MQL cooling technique gave better properties compare to conventional cooling. In addition to all those thing grey relational analysis (GRA) method was applied to determine the optimal solution. It clearly show that MQL environmental condition is a better way of machining 17-4PH stainless steel.

Keywords*: Minimum quantity lubrication (MQL), conventional water soluble cutting oils, machining, 17-4PH stainless steel.*

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CHAPTER 1

INTRODUCTION

Machining is one of the most important process that is carried out in industry to develop product. Machining involves removal of materials from a workpiece using cutting tool with control. It has benefited in many ways by developing various product for us but has some limitations. The limitation include generation of heat during machining which is a loss of supplied energy. The maximum energy supplied is converted into heat energy has to be minimised because the heat generation ultimately affect the product. There are various techniques have been developed to dissipate the generated heat during machining. The cooling techniques include flood cooling, cryogenic cooling and minimum quantity lubrication (MQL) system. Purpose of an ideal cooling techniques includes-

1. Cooling the chip-tool and tool-workpiece interface.

2. Flushing the chip away from the machining zone.

3. Easy disposable.

Demerits of conventional cooling techniques:

1. It uses huge amount of coolant.

2. If operator repeatedly come in contact with coolant than the operator may develop skin problem.

3. There is disposal problem of the used coolant.

1.1 Flood Cooling

The conventional way of machining where a huge amount of coolant is used. Although it has been testified from past research as the better way of dissipating heat from machining zone but it has other drawbacks. The drawbacks because of which this cannot be preferred are serious as they causes skin disorder and environmental problem. Except cooling effect it does not fulfil any coolant property.

It has more demerits compare to its benefits. There is always a problem of disposal of cutting fluid after machining which is hazardous to the environment.

1.2 Minimum Quantity Lubrication (MQL)

To minimise the set back in the flood cooling system anew technique has been developed which uses minimum quantity of cutting fluid.

The minimum quantity lubrication (MQL) has replaced the conventional way of cooling that is machining in flood cooling system. The flood cooling uses huge amount of lubricant yet does not satisfy all conditions of ideal cooling techniques. It cannot be easily disposable at the same time not environmental friendly. If one operator repeatedly come in contact with the flood cooling system operator may develop skin problem. As the name suggest MQL system uses less amount of lubricant and there is no disposal problem. MQL system includes mixture of high pressurised air with oil is being used as the lubricant in machining. The high pressurised (6bar) air is mixed with oil in the mixing chamber and directly supplied to the machining zone through nozzle. It is also called as “near dry machining” or “spatter lubrication” as it uses less amount of cutting fluid. No disposal problem in MQL system as the cutting fluid evaporated by gaining heat generated during machining.

The product obtained should be of good quality and the machining work need to be economical than only it will be considered as the process of machining as the best way of manufacturing product. To make the product of best quality it has to decrease the surface roughness at the same time minimise the cost of machining. Machining of best product includes good surface roughness and product of best desired shape and size for that purpose we need to increase the heat dissipation from machining zone to make a best product.

The methodology includes mixing of high pressurised (6bar) air with cutting fluid in a mixing chamber and directing the mixture to the cutting zone with a nozzle. Here the lubricant evaporated by gaining heat from the machining zone so it is basically an evaporative heat dissipation cooling techniques.

<u>Advantages of MQL</u>

- More effective as it directly applied to the machining zone instead of machining environment.
- Almost a dry process as it involves less amount of cutting fluid. Machining environment remain clean so safe working environment.
- It does the purpose of cooling and lubricating. Cutting fluid does the purpose of lubrication whereas high pressurised gas helps in heat dissipation.
- High pressurised gas flushes away the chip from machining zone so making chip disposal easy.
- It has been proved that machining done in MQL has better tool life and surface finish.

MQL is of two types –

1. Mixing inside the nozzle

2. Mixing outside the nozzle

Mixing inside the nozzle involves mixing of cutting fluid with compressed air inside the nozzle just before directing the lubricant to the machining zone. Here the mixing chamber is present inside the nozzle as shown in Figure 1.1 where high pressurised air and oil through the oil control valve supplied to the nozzle. In nozzle the entire mixture is carried out and it is directed to the machining zone.

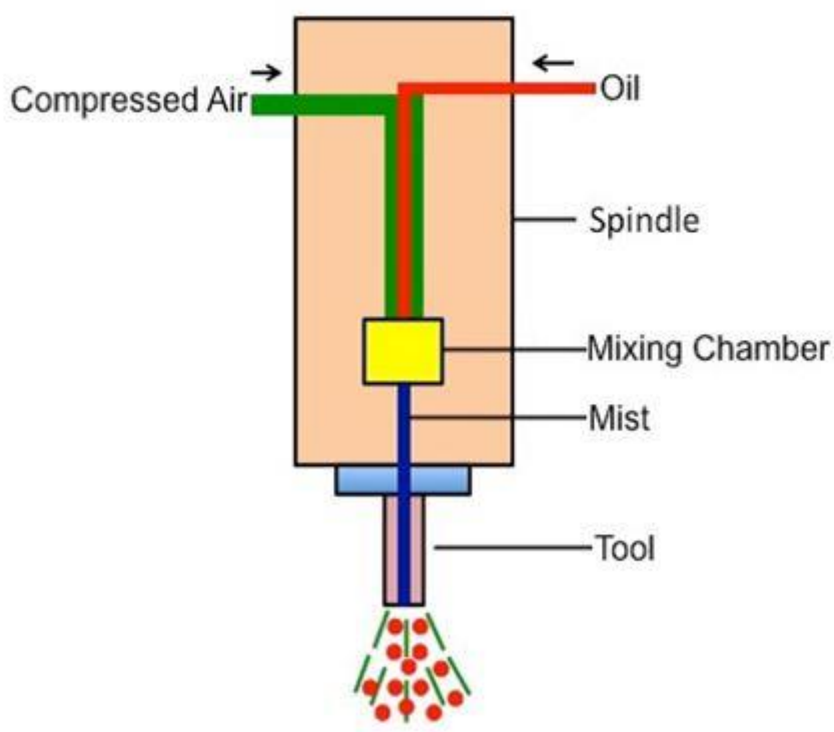

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Figure 1.1: MQL Mixing inside the Nozzle

In case of second one the conventional process of MQL cooling technique where the compressed air and the cutting fluid is mixed in a mixing chamber and the mixture is allowed to pass through the nozzle as shown in Figure 1.2. The mixing chamber where the mixture is done present in a separate place outside the nozzle and then it is supplied to the cutting zone.

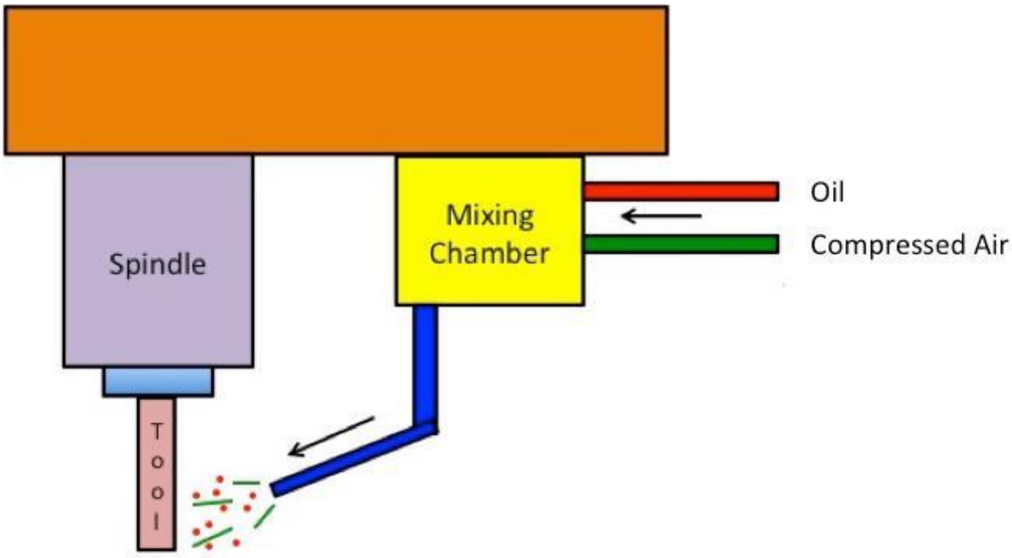


Figure 1.2: MQL Mixing outside the Nozzle

1.3 Cryogenic Cooling

Cryogenic means working temperature is less than 123K. Liquid nitrogen is generally used as cryogenic material. It is present two-third of atmosphere gases. It boils at -198.79º C and melts at-210.01º C. Nitrogen is an odourless, colourless and non-toxic gas. The cryogenic coolant is supplied to the machining area where cutting temperature is high where it absorbs the generated heat there by reducing the cutting temperature. As this lower the cutting temperature it helps in better product manufacturing. Unlike MQL cryogenic cooling system cannot be set everywhere and it is costly from set up point of view.

CHAPTER 2

LITERATURE REVIEW

The increasing demand in industries have increased its production rate which led to the case of high material removal rate, high surface finish and better dimensional accuracy. The high material removal rate process is fulfilled by using high depth of cut, high cutting velocity and feed rate. This high material removal rate and cutting parameters lead to development of high temperature in cutting zones. To minimise this heat generation various techniques have been used which adversely affect the final product and tool.

In the need of current technology many researchers have tried to develop one efficient and environmental friendly solution because all metal working fluid are hazardous and harmful for workers. Minimum quantity lubrication is one such technique which reduces the quantity of metal working fluid to be used to support green manufacturing.

Number of researchers have tried to find out the advantages of minimum quantity lubrication in machining processes. The effect of minimum quantity lubrication (MQL) technique on cutting forces, surface roughness, and chip-morphology and chip thickness was studied.

2.1 Cutting forces

The cutting velocity is one of the important parameter which affect the product and machining process. At constant depth of cut when feed was varied increase in cutting velocity led to decrease of cutting forces. The cutting forces increased with increase of cutting velocity because at high cutting velocity the heat generated was higher which resulted in tool wear acceleration as the diffusion and the adhesion wear increases and dominates. The accelerated tool wear hampered the cutting ability consequently increased in force[1]. When cutting velocity is 120m/min or high fully plastic chips are formed and there is bulk contact between tool rake surface and chips which prevent entering of any fluid into the chip tool interface resulting in increase of cutting force was investigated by B.Kumar, A. Sengole rayan volume 11, Issue 3 Ver. III(2014)[2]. Ling et al. observed that under all lubricating conditions cutting forces increases with increase in feed rate because as the feed rate increases the cutting area increases resulting in high cutting force [3].

Cutting forces decrease with speed under all lubrication conditions which is a significant effect on any machined components. MQL technique machining reduced the cutting forces because of reduction of friction because of lubrication effect of MQL jet (may be reduction in chip load) [4]. He et al. investigate that turning of bearing steel GCr15 at high cutting velocity under different cooling environment highly pressurised oil-mist mixture could penetrate into the cutting zone resulted in reduction of cutting forces compare to other cooling technique [5]. When Hadad and Sadeghi compared the machining of AISI 4140steel under different cooling techniques observed that MQL gave the least value of cutting forces compare to Flood cooling and dry machining gave the Highest value of cutting forces[6]. Dhar et al. found that cutting force and feed force increased significantly under MQL environment with increase in cutting velocity[7].

Kishawy et al. experimented on aluminium alloy A365 on cutting environment of dry, flood and minimum quantity lubrication (MQL).The cutting forces obtained under MQL environment were marginally higher than the forces developed under flood cooling environment [10].

Li and Liang observed extensively study of machining parameters on process parameters under MQL technique machining. It was found that application of MQL during machining reduced the tangential cutting forces to a significant limit when machining is done at low cutting velocity [13].

2.2 Surface roughness

Surface roughness determined the quality of product lower the surface roughness the better is the dimensional accuracy of the machined product. Hence during machining surface roughness is an important parameter which need to be considered.

Surface finish depends upon the cutting conditions and cutting environment. Surface roughness decrease with increase in cutting velocity. In case of MQL cutting system surface roughness decreased 15-40% compared to dry machining. This was because in MQL the tiny sprayed coolant reached to the tool-workpiece environment and formed a thin layer which prevented abrasion wear and the formation built up edge which significantly contribute to the surface finish[1]. B Kumer, A.Sengole rayan Volume11 Issue 3 Ver.III(2014) investigate that when cutting velocity is as high as 120m/min plastic chips are formed preventing flow of cutting fluid into chip-tool hot interface. When cutting velocity is low and feed is high than chip-tool contact is partially elastic which affect the surface finish of machined surface [2].

During their investigation He et al. found that under MQL environment surface roughness decreases compare to other cooling environment [5]. Poor surface finish obtained for machining under dry environmental conditions whereas least amount of surface roughness was observed for machining under MQL technique. This was because machining under MQL technique resulted in lesser cutting forces hence reduces the heat generation and maximum temperature of the chip tool interface [6]. Dhar et al..found that MQL technique resulted in better surface finish in his study of effect of MQL and dry machining on AISI 1040. This was because of improved tool life and reduction in temperature during machining under MQL as a result better surface finish [7]. Khan et al. observed in the turning of AISI 9310 that surface finish improved in case of MQL compared to wet and dry machining because of increased tool life [8]. Sharma and Sidhu investigate the effect of dry machining and machining with

MQL technique on the surface finish of AISI D2 steel. It was found that machining under MQL technique gave better surface finish as compared to dry machining. This was because dry machining causes adhesive and diffusive wear which deteriorates the surface finish of the final workpiece as the temperature generated during dry machining was high[11].

2.3 Tool life

In machining tool life is the criteria which need to be considered as this will make the machining process economical and limit the repeated change of tool to carry out further machining. Dhar et al. experimented on AISI 1040 steel under dry and MQL lubricating techniques. MQL techniques machining resulted in less auxiliary flank wear therefore tool life increased [7].

Due to considerable reduction in the cutting temperature under MQL environment led to reduction in tool wear [13]. Lubricating the rake surface with MQL gave same result as that of dry machining when their tool life were compared. But instead of rake surface if flank surface was lubricated than the tool life increased compared to dry machining. It has one demerit of lubricant reaching to cutting surface when machining [14.]

2.4 Temperature

Temperature generated during machining is the parameter which control tool life, surface roughness, tool wear and quality of product etc. Many researchers have tried to find out the effect of temperature during machining using various machining parameters. Sharma and Sidhu observed the effects of dry and MQL technique during the machining of AISI D2 steel with carbide tool. It was found that reduction of temperature to a significant amount occurred during machining using minimum quantity lubrication as compared to dry machining with all machining process parameters [11].

Li and Liang investigated to find the performance of MQL machining on various process parameters. Temperature was found to less almost under all cutting velocity when machining is done with MQLenvironment[13].

2.5 Chip morphology

The form of chip produced is one of the parameter which influenced the metal cutting industry. MQL technique has increased the chip thickness ratio. Lubricating and cooling effect of MQL technique minimises the shear zone shrinkage and plastic deformation which reduced built up edge formation.

During machining of AISI 1040 Dhar et al. investigated the machining techniques of dry , MQL and wet machining. The study of chip morphology indicated that discontinuous and light coloured chips were produced with MQL conditions [9]. Vasu and Reddy investigated on Inconel 600 alloy by using minimum quantity lubrication and compared the process parameters under dry and MQL. The chip morphology observed that light coloured chips were formed when machined with MQL whereas brown coloured chips were formed with dry machining [12].

2.6 Objective

From the literature review of past work it has observed that much work has been done on MQL. Using MQL techniques machining processes were reported like milling, turning, grinding etc. The effect of various cutting parameters has been investigated like cutting forces, co-efficient of friction, surface roughness and chip reduction coefficient. In the current work there is a comparison of various process parameter using MQL and flood cooling technique. To understand the benefits of MQL technique on 17-4 PH stainless steel the work is focused upon.

The following objective has been studied in the current work:

1. To investigate the effect of cutting velocity, feed and depth of cut using Taguchi L9 orthogonal array method on cutting forces, surface roughness and chip reduction co-efficient under flood cooling environment.

2. To study the various process parameters using Taguchi L9 orthogonal array based design with machining parameters like depth of cut, feed and cutting velocity based on MQL technique.

3. To study the comparative effect of machining parameters on process parameters using MQL and flood cooling technique.

4. To optimize various output using grey relational analysis to obtain the best possible combination of machining parameters to obtain better result.

CHAPTER 3

EXPERIMENTAL SETUP

The turning experiment was done using a heavy duty lathe machine (Maker: Hindustan Machine Tools (HMT) Ltd.). The experiment was done on a cylindrical job of stainless steel (17-4PH).The workpiece on which the entire experiment was carried out with 42 mm in diameter and 400 mm in length. The turning experiment was carried out on conventional cooling conditions and minimum quantity lubrication (MQL) system conditions.

Figure3.1: Experimental set-up for conventional cooling.

Figure 3.2: Experimental set-up for MQL lubrication system

3.1 Workpiece and Tool material selection

All the turning operations were carried out on 17-4PH stainless steel. The metal is used as different aerospace application, chemical processing equipment. This also used as refining equipment for oil, petroleum and equipment for food processing. The chemical composition of the steel are shown in Table 3.1 and physical properties in Table 3.2.

Table 3.1: Chemical composition of 17-4PH stainless steel.

Elements	C	Mn	P	S	Si	Cr	Ni	Cu	Nb & Ta
Wt%	0.07	1	0.04	0.03	1	17	4	3-5	0.15-0.45

Table 3.2: Physical properties of 17-4 PH stainless steel

Physical Properties	Values
Density	7810kg/m^3
Poisson's Ratio	0.29
Elastic Modulus	196GPa
Ultimate Tensile Strength(UTS)	1103MPa
Yield Strength	1000MPa
Specific Heat	460J/kg-K
Thermal conductivity	18.3W/m-K
Rockwell Hardness	35

The machining was carried out using uncoated cemented carbide tool insert.

3.2 MQL set up

To conduct the turning experiment using minimum quantity lubrication (MQL) technique set up was developed and shown in Figure 3.3. The oil-mist mixture was supplied to the cutting zone with high pressure for machining.

Figure 3.3: Unit for MQL

3.3 MQL Techniques Working Principle

Highly compressed air is supplied into the air filter from a compressor through a solenoid valve. All the impurities are filtered that may present in the supplied air to keep it clean and dirt free. During this process oil control valves guided the oil to the mixing chamber. In mixing chamber the oil and the filtered air mixed to form oil-mist. The prepared oil-mist mixture is supplied to the cutting zone through a nozzle.

Experiment Design

The experimental design was based on Taguchi L9 orthogonal array for further optimization of result using grey relational analysis as shown in Table3.3. The turning process was carried out at a constant length of cut of 15mm for all runs to study the effect of variations of cutting velocity, depth of cut and feed. The cutting velocity was varied over three levels: 40m/min, 70m/min and100m/min. The depth of cut was varied as 0.5mm, 1mm and 1.5mm whereas the feed was varied as 0.08mm/rev, 0.14mm/rev and 0.20mm/rev.

Table 3.3: Experimental design using Taguchi L9 orthogonal array method.

Run no	Cutting velocity(m/min)	Feed(mm/rev)	Depth of cut(mm)
1	47	0.08	0.5
2	47	0.14	1
3	47	0.20	1.5
4	61	0.08	0.5
5	61	0.14	1
6	61	0.20	1.5
7	103	0.08	0.5
8	103	0.14	1.0
9	103	0.20	1.5

The turning of 17-4PH stainless steel was carried out under the following experimental conditions as summarised in Table 3.4.

Table 3.4: Experimental conditions for turning operation.

Workpiece Material	17-4PH stainless steel
Tool Insert	Uncoated cemented carbide insert
Cutting velocity(m/min)	47,61,103
Feed(mm/rev)	0.08,0.14,0.20
Depth of cut(mm)	0.5,1.0,1.5
Length of cut(mm)	15
Environment	MQL

During machining operation the cutting forces were measured as the output. The cutting forces were measured with the help of a dynamometer (maker: Kistler Instrument Co.)as shown in Figure 3.4.

Figure 3.4: Dynamometer for cutting forces measurement

After machining the workpiece surface roughness was measured using a profilometer (maker: Taylor Hobson: Sutronic)as shown in Figure 3.5. Surface roughness for each length of cut was measured by mounting the prrofilometer on the workpiece by using horizontal support. For each run chips were collected and chip thickness was measured to calculate chip-reduction coefficient with the help of digital vernier calliper.

Figure 3.5: Talysurf or Profilometer for surface Roughness measurement

3.4 Grey Relational Analysis

The grey relational analysis is a multi-response optimization technique. A black system means a system with no information whereas a white system represent availability of allthe related information. Grey system is one which is in between of black and white system as all information are not available. To optimise a system using grey relational analysis (GRA) following steps are followed:

3.4.1. Normalisation of Output

All the output responses were normalised between 0and 1. Normalisation was done according to 'higher the better characteristics' for responses which needed to maximize and 'lower the better' for the output responses which needed to minimise. But here cutting forces, surface roughness and coefficient of friction need to be minimised so 'lower the better' normalisation system will be used. To normalize the output following equation will be used.

$$Xi(k) = \frac{maxyi(k) - yi(k)}{maxyi(k) - minyi(k)} \quad (1)$$

Where i=1,2,3….m, k=1,2,3……n, m is the total number of experiment and n is number of output; maxyi(k) and minyi(k) are the maximum and minimum values of output responses where Xi(k) is the normalised value.

3.4.2 Calculation of Grey Relational Co-efficient

Grey relational coefficient is calculated for the normalised data of output responses. It is calculated by using the following equation.

$$\xi i(k) = \frac{\Delta min - \zeta \Delta max}{\Delta i(p) + \zeta \Delta} \qquad (2)$$

ξ(k) is the grey relational coefficient. ζ is the distinguishing factor whose value lies between 0 to 1, but for convenient taken as 0.5. Δmin and Δmax are the minimum and maximum normalised output.

3.4.3 Grey Relational Grade

Grey relational grade is calculated as sum of grey relational coefficient per number of output. Higher the value of grey relational grade high is the effect of parameter on the original experiment and vice versa. Therefore, the combination with higher value of grey relational grade is the optimal combination to carry out the experiment. It is calculated using following relation:

$$yi = (1/n) \sum_0^n \xi i(k) \qquad (3)$$

The grey relational analysis result is verified by conducting experiment with the corresponding optimal parameters.

CHAPTER 4

RESULT AND DISCUSSION

After machining, the output responses were measured and tabulated as shown in Table4.1 and 4.2.

Table 4.1: out responses for turning under flood cooling environment

Run No	Vc (m/min)	F (mm/rev)	t (mm)	Fz (N)	Fy (N)	Fx (N)	Ra (µm)	Rt (µm)	Rz (µm)	€	µ
1	47	0.08	0.5	220	134	105	2.266	14.66	11.33	2.4071	0.22534
2	47	0.14	1	442	190	243	1.866	15	9	2.2777	0.21116
3	47	0.2	1.5	651	215	392	1.933	13.66	10.666	1.8066	0.151722
4	61	0.08	1	338	170	223	1.933	19.66	10	2.21127	0.19187
5	61	0.14	1.5	540	222	375	2.266	18	12.666	2.36651	0.22097
6	61	0.2	0.5	290	180	120	3.4	12.66	11.33	1.65648	0.129468
7	103	0.08	1.5	354	220	335	1.866	13.33	9	2.56244	0.24138
8	103	0.14	0.5	207	187	100	1.666	13.66	9	1.4642	0.09781
9	103	0.2	1	524	212	261	1.866	12	9.666	2.1327	0.19429

Table 4.2: output responses for turning under MQL

Run No	Vc (m/min	F (mm/rev)	t (mm)	Fz (N)	Fy (N)	Fx (N)	Ra (µm)	Rt (µm)	Rz (µm)	€	µ
1	47	0.08	0.5	210	130	100	3.666	29.66	12	1.993011	0.176913
2	47	0.14	1	421	186	258	1.6	11	9.666	2.529211	0.23803
3	47	0.2	1.5	674	237	400	1.733	10.66	9.33	2.18449	0.20044
4	61	0.08	1	307	160	225	1.533	12	7.33	3.3907	0.31323
5	61	0.14	8	520	214	379	1.8	10.66	9	2.11507	0.19216
6	61	0.2	0.5	280	170	116	3.466	28.66	16	2.0602	0.185419
7	103	0.08	1.5	334	200	325	1.2	11	6.33	2.30361	0.214067
8	103	0.14	0.5	220	165	105	1.266	7.66	6	1.61218	0.122514
9	103	0.2	1	512	220	273	1.933	11.33	9.333	1.03012	0.00761

Effect of cutting conditions on various machining characteristics under flood cooling and MQL cooling techniques.

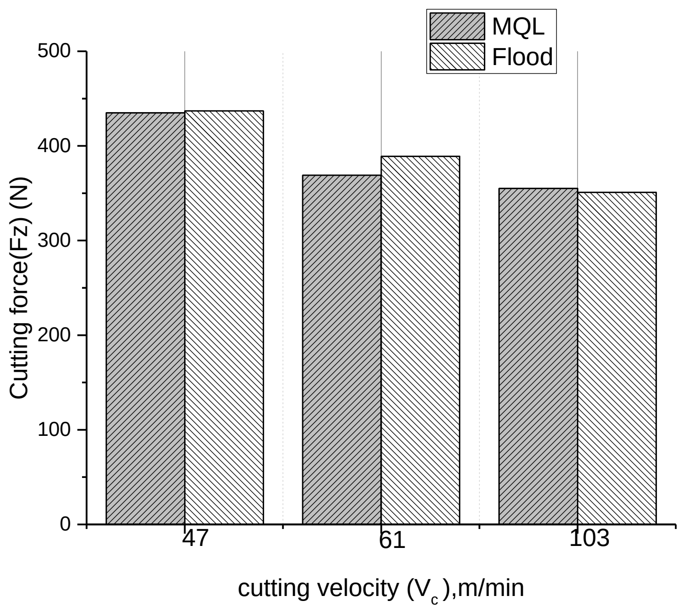
The output responses were plotted for a various process parameters with machining parameters. The output responses considered were cutting forces, surface roughness and chip reduction co-efficient friction. Thus for output response effect of each process parameter was studied under all lubricating environment.

4.1 Effect on Cutting Forces

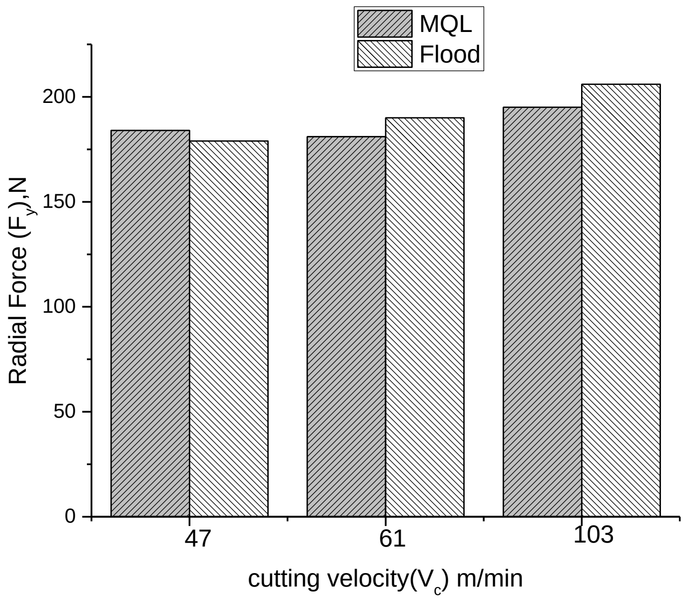
Cutting forces have significant characteristics on the power required for machining operation. If this can be reduced than the consumed power will be less and economically. The variation of cutting forces with different machining parameters were studied as follows:

4.1.1 Cutting velocity

As the plot describe that with increasing cutting velocity cutting force decreases under flood cooling because increase in cutting velocity prevents formation of built up edge as the pressure energy of flood cooling system dislodged the built up edge (BUE)[9]. Figure 4.1(a) shows cutting force is high in case of MQL machining at high cutting velocity compare to flood cooling because the capillary action prevented which resulted in decrease of cooling effect. But with increase in cutting velocity it was observed that there no such significant differences in forces under the machining condition of flood cooling environment and MQL environment from Figure 4.1 (a),(b), and(c).



(a)



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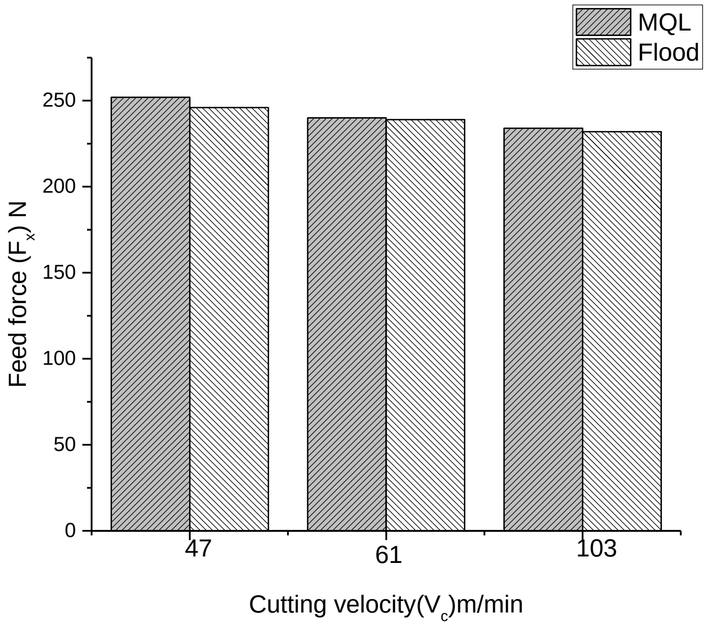
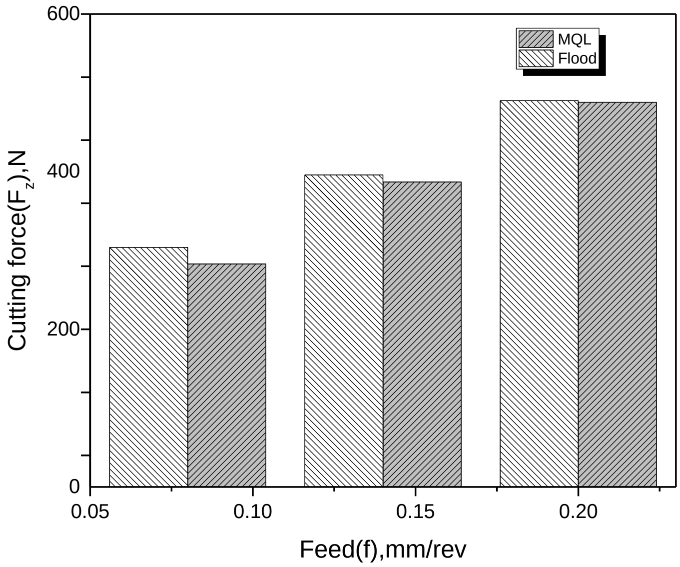


(c)

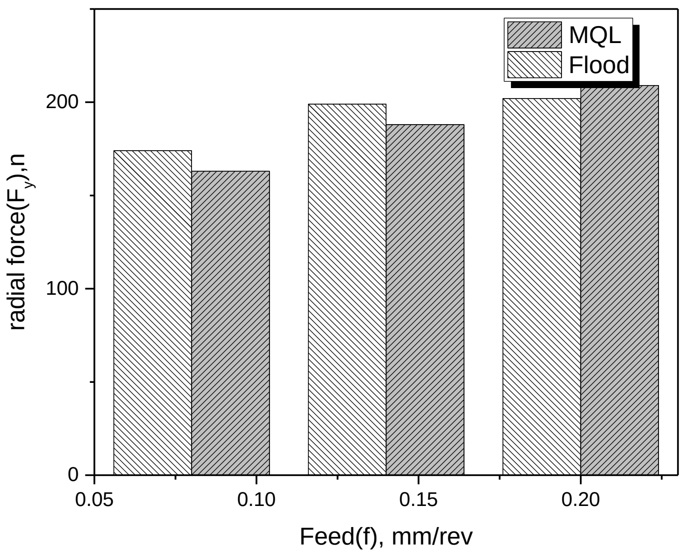
Figure. 4.1: Plot showing variation of cutting forces with cutting velocity (a) cutting force, (b) radial force and (c) feed force

4.1.2 Feed

From the Figure 4.2 it is observed that cutting forces increased with the feed rate because of thermal softening of meatal [8, 10]. But when we compare the cutting forces obtained from flood cooling and MQL environment, flood cooling system shows better effect with lower cutting forces. From the Figure4.2 (a), (b), and (c) it is observed that there is marginal difference between the cutting forces in case of flood cooling and MQL cutting environment. In low feed rate the cutting forces developed were minimum in case of MQL environment machining because at low feed rate high pressurised MQL impingement can penetrate into the cutting zone which reduced the cutting forces. But at high feed rate penetration of coolant into the machining zone is not that effective hence cooling effect of flood coolants heat dissipating rate predominant over the penetration rate of MQL cooling system. This reduction in cutting forces is comparable.



(a)



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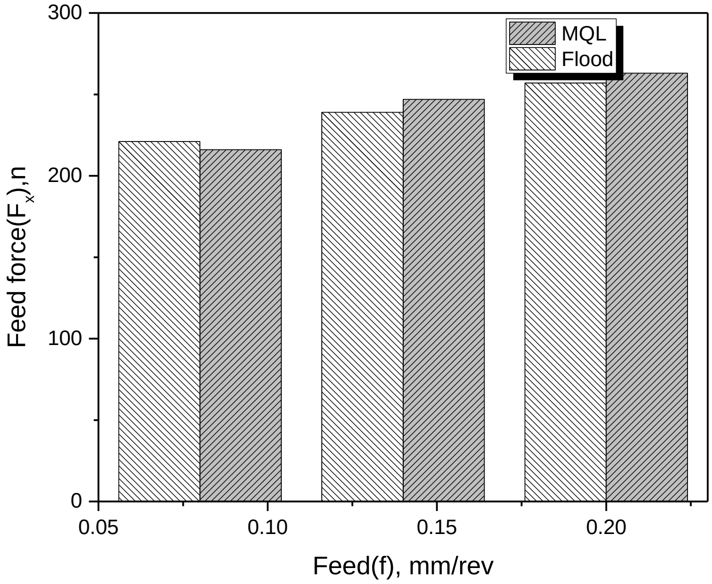
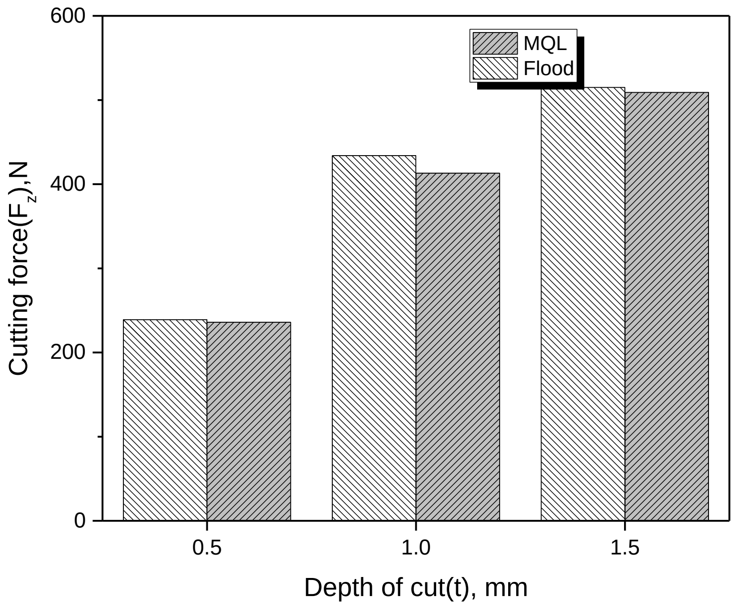


(c)

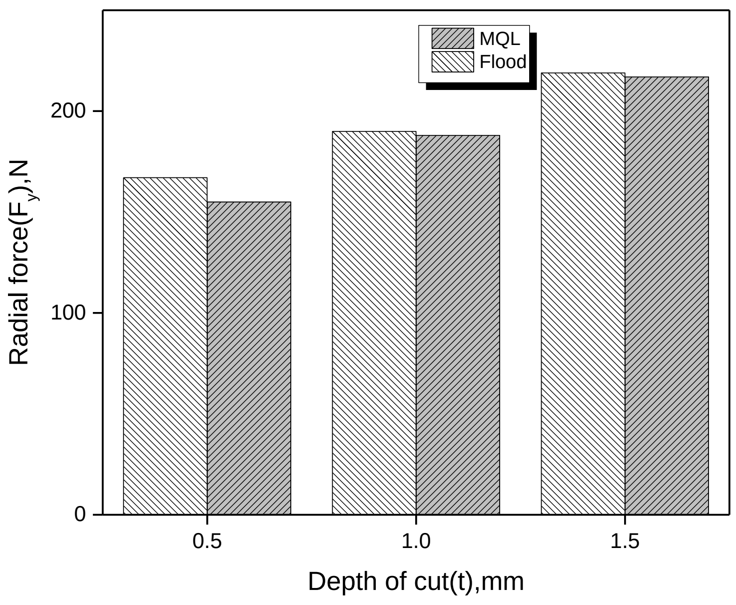
Figure 4.2: Plot showing variation of cutting forces with feed (a) cutting force, (b) radial force and (c) feed force

4.1.3 Depth of cut

Figure 4.3 display that cutting forces increases with increased depth of cut .But when we compare the machining environment of the system observed it was observed that in MQL environment cutting force generated were low with respect to flood cooling environmental cooling conditions.



(a)



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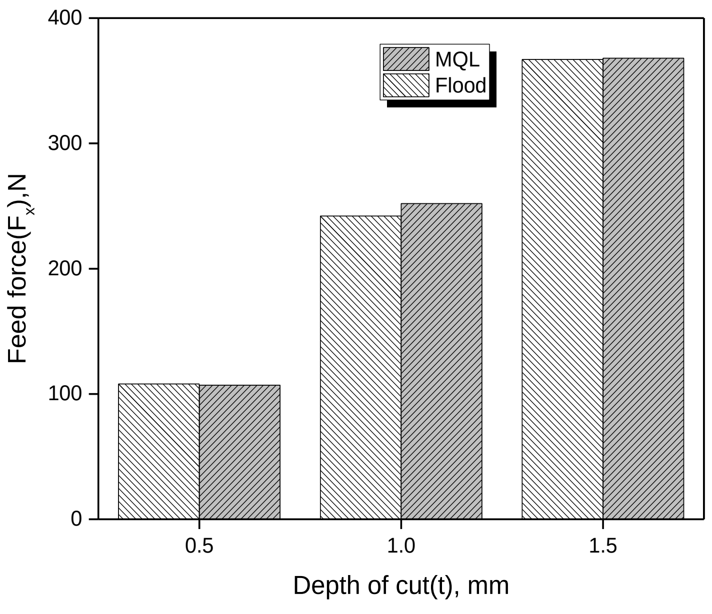


(c)

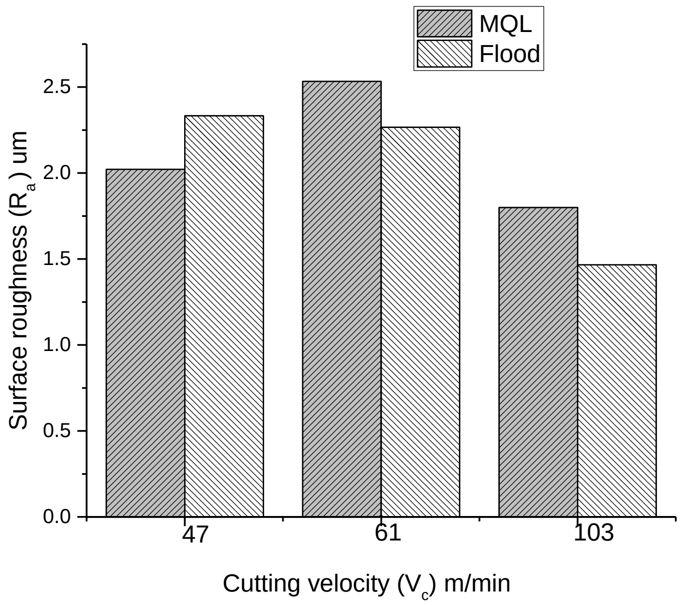
Figure 4.3: Showing variation of cutting forces with depth of cut (a) cutting force, (b) radial force and (c) feed force

4.2 Effect on Surface Roughness

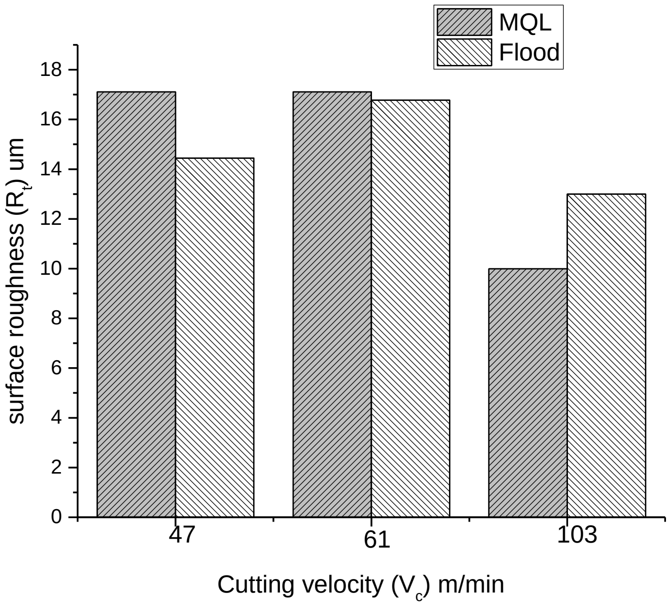
Surface finish determine the quality of product obtained after machining. The better the surface finish better is the quality of product. The variation of surface roughness with different machining parameter were studied below.

4.2.1 Cutting velocity

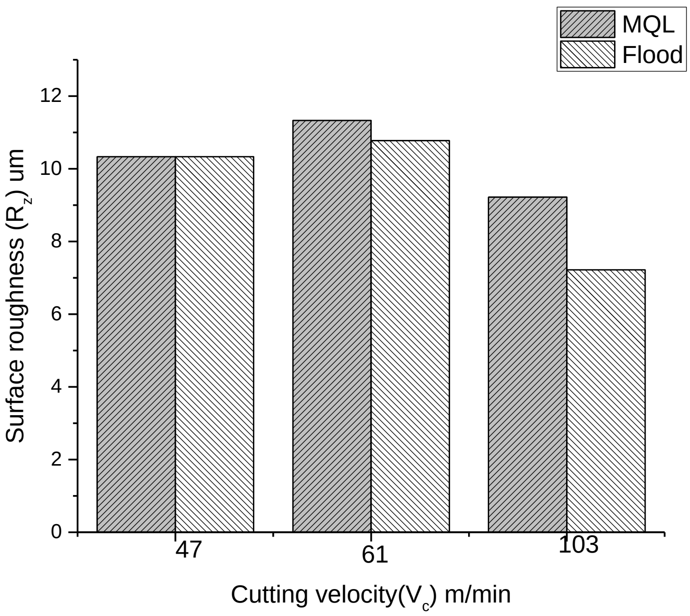
From Figure 4.4 surface roughness found to decrease with increase of cutting velocity because at high cutting velocity the formation of built up edge is prevented and the abrasive wear reduced [9] as the coolant could easily entered into chip-tool interface forming a thin layer. The Figure 4.4 (a), (b) and (c) follow the trend that increase in cutting velocity led to decrease in surface roughness.



(a)



(b)

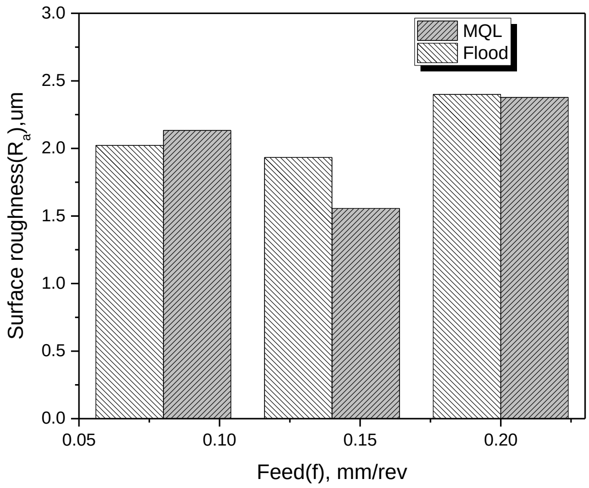


(c)

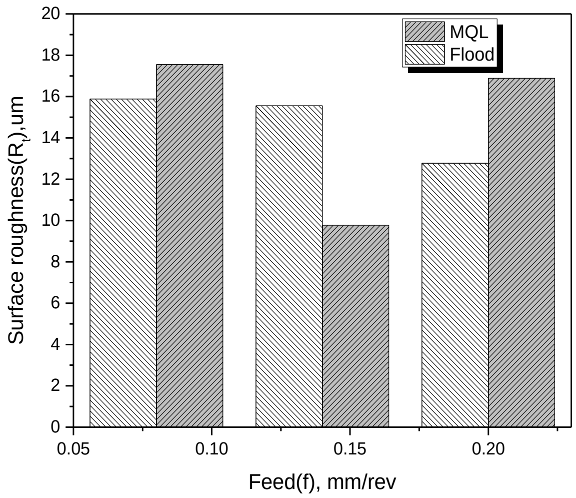
Figure 4.4: showing variation of surface roughness with cutting velocity (a) R_a , (b) R_t and(c) R_z

4.2.2 Feed

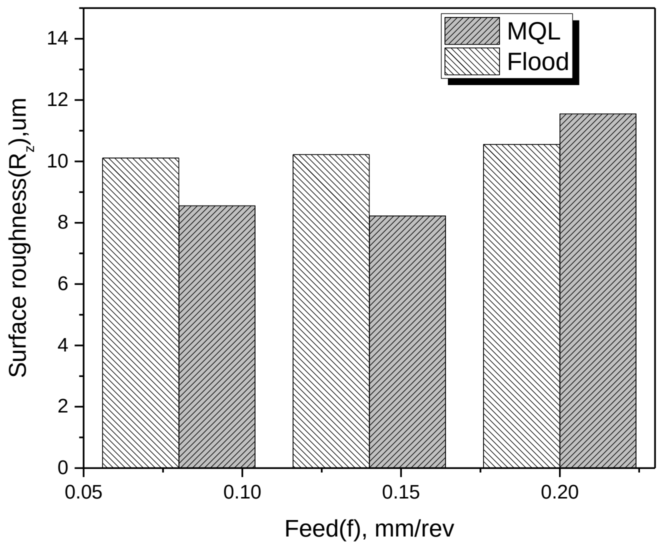
Figure 4.5 depicts that at low feed rate flood cooling system give better surface finish but increase in feed rate led to increase in surface roughness. As from the Figure 4.5 (a), (b) and (c) increase in feed rate decrease R_t and R_z values but R_a increases.



(a)



(b)

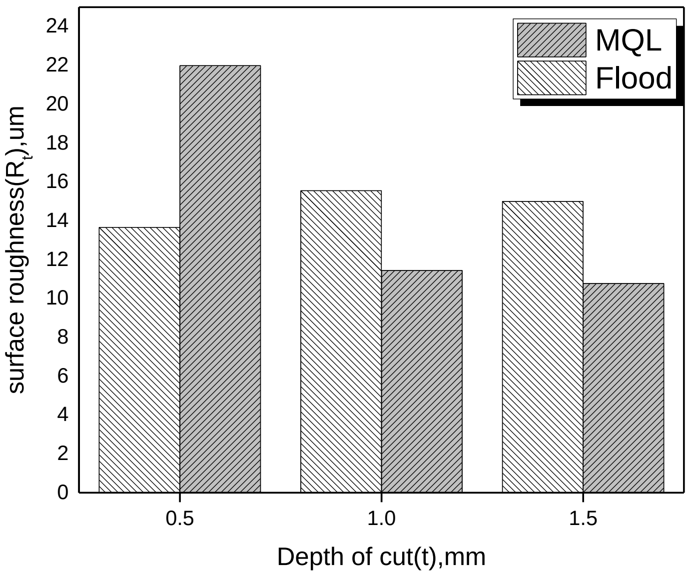


(c)

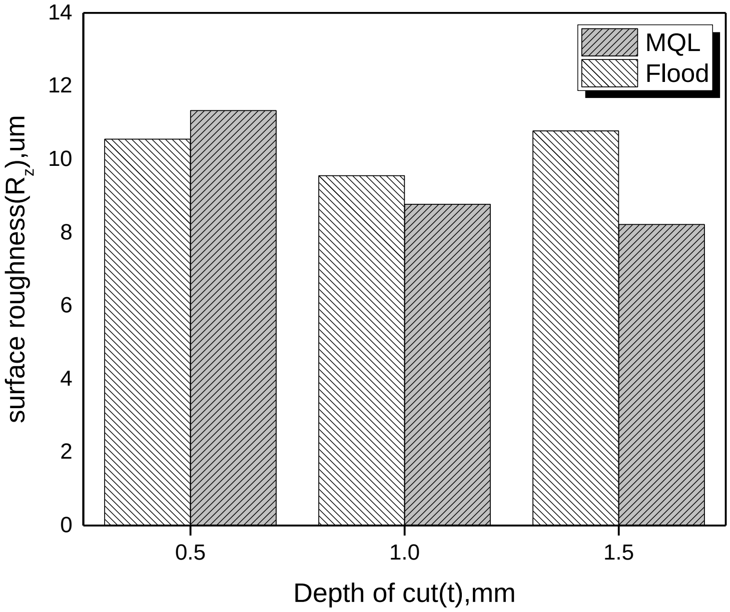
Figure 4.5: showing variation of surface roughness with feed (a) R_a , (b) R_t and(c) R_z

4.2.3 Depth of cut

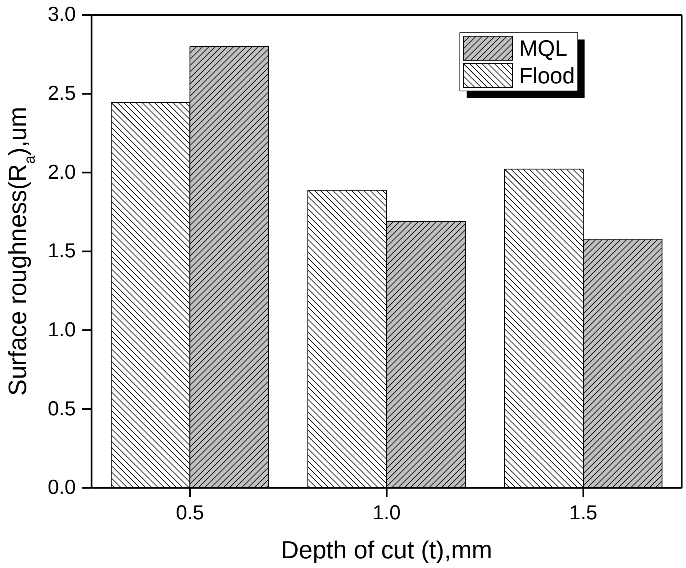
At low depth of cut MQL environmental machining conditions gave poor surface finish compared to flood cooling environment. But as depth of cut increased MQL environment became superior to the flood cooling when surface roughness property is considered. Figure 4.6 (a), (b) and (c) show that surface roughness decreased when depth of cut was increased but in all cases MQL lubricating environment showed better result compared to flood cooling.


MQL
Flood
surface roughness(Rt),um
24
22
20
18
16
14
12
10
8
6
4
2
0
0.5
1.0
1.5
Depth of cut(t),mm

(a)


MQL
Flood
surface roughness(Rz),um
14
12
10
8
6
4
2
0
0.5
1.0
1.5
Depth of cut(t),mm

(b)



(c)

Figure 4.6: showing variation of surface roughness with depth of cut (a) R_a , (b) R_t and(c) R_z

4.3 Chip Reduction Co-efficient

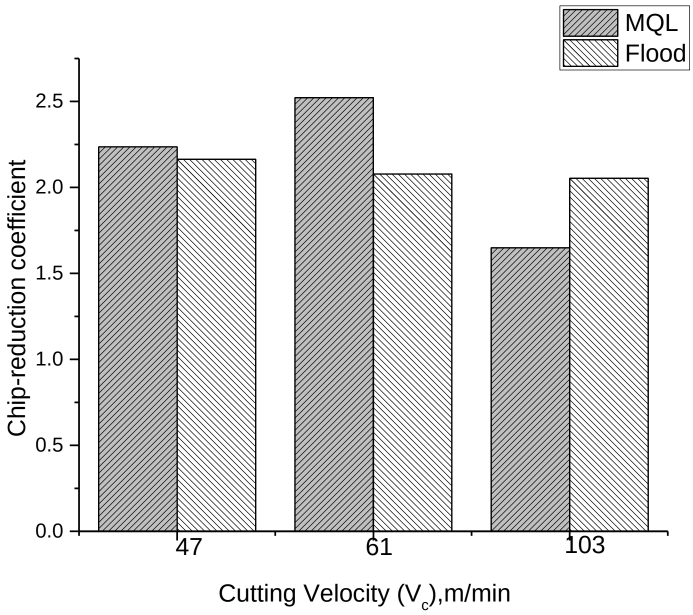
The ratio between chip thickness after cut to the thickness of uncut layer (chip before cut) is termed as chip reduction co-efficient. Greater the value of chip reduction coefficient more forces or energy required for machining. Hence lower the value of chip reduction co-efficient it will be better but productivity should not be hampered to reduce the chip reduction co-efficient.

Figure 4.7 (a) depicts that chip reduction co-efficient decreases with increase of cutting velocity.

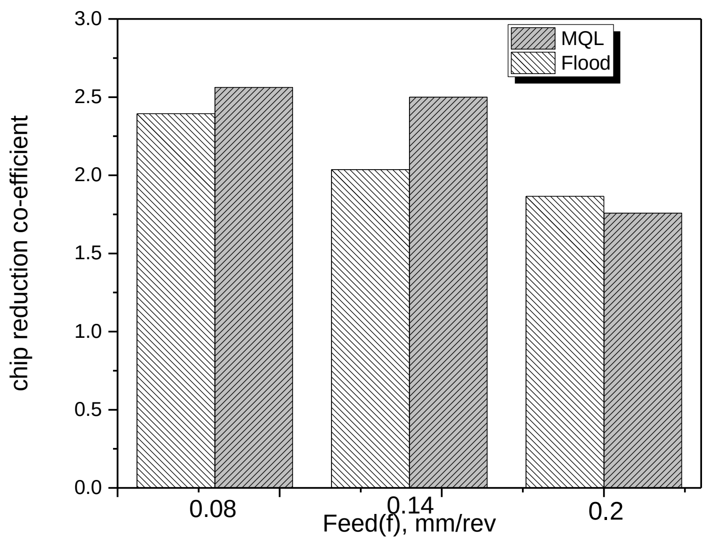
When machining environment are compared at low cutting velocity Flood cooling system gave better result with respect to MQL system. At high cutting velocity MQL gave better result.

With increase in feed rate chip reduction coefficient decreases. Comparing flood cooling environment and MQL system obtain that MQL has better effect on reducing chip reduction co-efficient compare to flood cooling environmental conditions in Figure 4.7 (b).

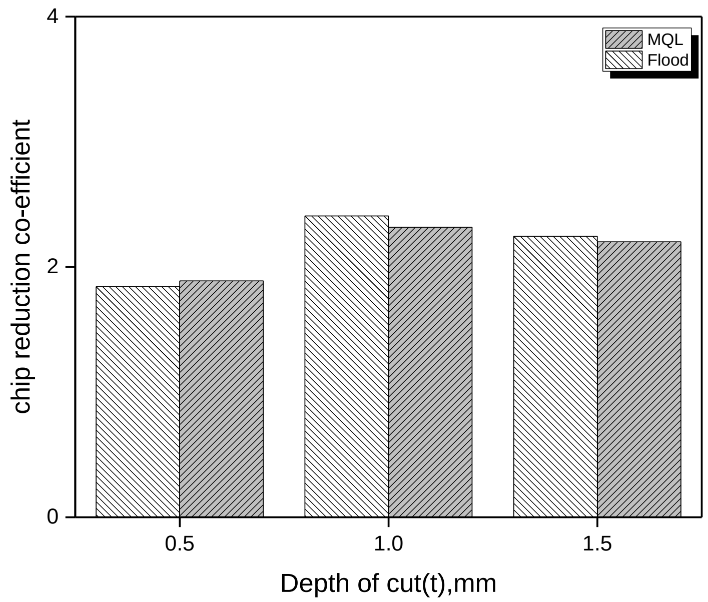
Figure 4.7 (c) show that when chip reduction co-efficient is compared with depth of cut first it increases the chip reduction co-efficient but after that depth of cut lower the chip reduction co-efficient. If the chip reduction coefficient is compared with machining environment MQL system gave better result.



(a)



(b)



(c)

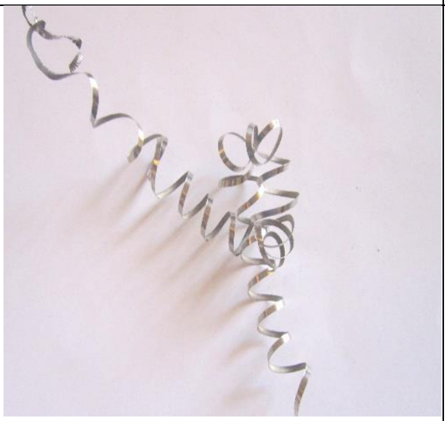
Figure 4.7: showing variation of chip-reduction co-efficient with machining parameters (a) cutting velocity, (b) feed and(c) depth of cut

4.4. Chip Morphology

After machining each run chips were collected to find out chip-reduction coefficient and study the details of chip formation pattern in each run. The collected chips were photographed to study the details of it as shown in Table 4.3.

Table 4.3: Study of chip morphology

Run No.	Conditions	Flood Cooling	MQL
1	RPM=357rev/min Feed=0.20mm/rev Depth of cut=1.5mm		
2	RPM=465rev/min Feed=0.14mm/rev Depth of Cut=1.5mm		

3	RPM=787rev/min Feed=0.08mm/rev Depth of Cut=1.5mm		
4	RPM=357rev/min Feed=0.14mm/rev Depth of cut=1mm		
5	RPM=465rev/min Feed=0.08mm/rev Depth of Cut=1mm		
6	RPM=787rev/min Feed=0.20mm/rev Depth of Cut=1mm		

7	RPM=357rev/min Feed=0.08mm/rev Depth of Cut=0.5mm		
8	RPM=465rev/min Feed=0.20mm/rev Depth of Cut=0.5mm		
9	RPM=787rev/min Feed=0.14mm/rev Depth of Cut=0.5mm		

It was found that almost in all cases chips formed are continuous. But the chips produced under high depth of cut and feed found to be discontinuous and ‘C’ type.

4.5 Grey Relational analysis (GRA)

From the analysis of above graphs, it is clear that MQL cutting environment is producing better result by minimising cutting forces, surface roughness and chip reduction coefficient. The output table of the cutting conditions is shown in Table 4.4.

Table 4.4: Result table for MQL environmental conditions

Run no	V_c m/min	F mm/rev	Depth of cut mm	F_z N	R_a μm	μ
1	47	0.08	0.5	210	3.666	0.176913
2	47	0.14	1	421	1.6	0.23803
3	47	0.2	1.5	674	1.733	0.20044
4	61	0.08	1	307	1.533	0.31323
5	61	0.14	8	520	1.8	0.19216
6	61	0.2	0.5	280	3.466	0.185419
7	103	0.08	1.5	334	1.2	0.214067
8	103	0.14	0.5	220	1.266	0.122514
9	103	0.2	1	512	1.933	0.00761

After finding the output the output responses are normalised using equation 1 and tabulated in Table 4.5.

Table 4.5 Normalisation of output responses

Run no	F_z (N)	R_a (μm)	μ
1	1	0	0.446034
2	0.545259	0.837794	0.246057
3	0	0.783861	0.369053
4	0.790948	0.864964	0
5	0.331897	0.756691	0.396146
6	0.849138	0.081103	0.418202
7	0.732759	1	0.324465
8	0.978448	0.973236	0.62403
9	0.349138	0.702758	1

From the normalised table grey relational co-efficient and grey relational grade are evaluate using equation 2 and 3 in Table 4.6. After calculating grey relational grade they are ranked according to their values. The combination which give highest value of grey relational grade is the optimal set of parameter for machining.

Table 4.6: Grey Relational analysis

Run no	F_z (N)	R_a (μm)	μ	Grey relational grade	Rank
1	1	0.333333	0.474399	0.602577	5

2	0.523702	0.755052	0.398742	0.559165	6
3	0.333333	0.698188	0.442107	0.49121	9
4	0.705167	0.787356	0.333333	0.608619	4
5	0.428044	0.672668	0.452958	0.51789	8
6	0.768212	0.352386	0.462194	0.527597	7
7	0.651685	1	0.425338	0.692341	2
8	0.958678	0.949192	0.570796	0.826222	1
9	0.434457	0.627162	1	0.687206	3

Mean effective plot of Grey relational analysis is shown in figure 4.8.

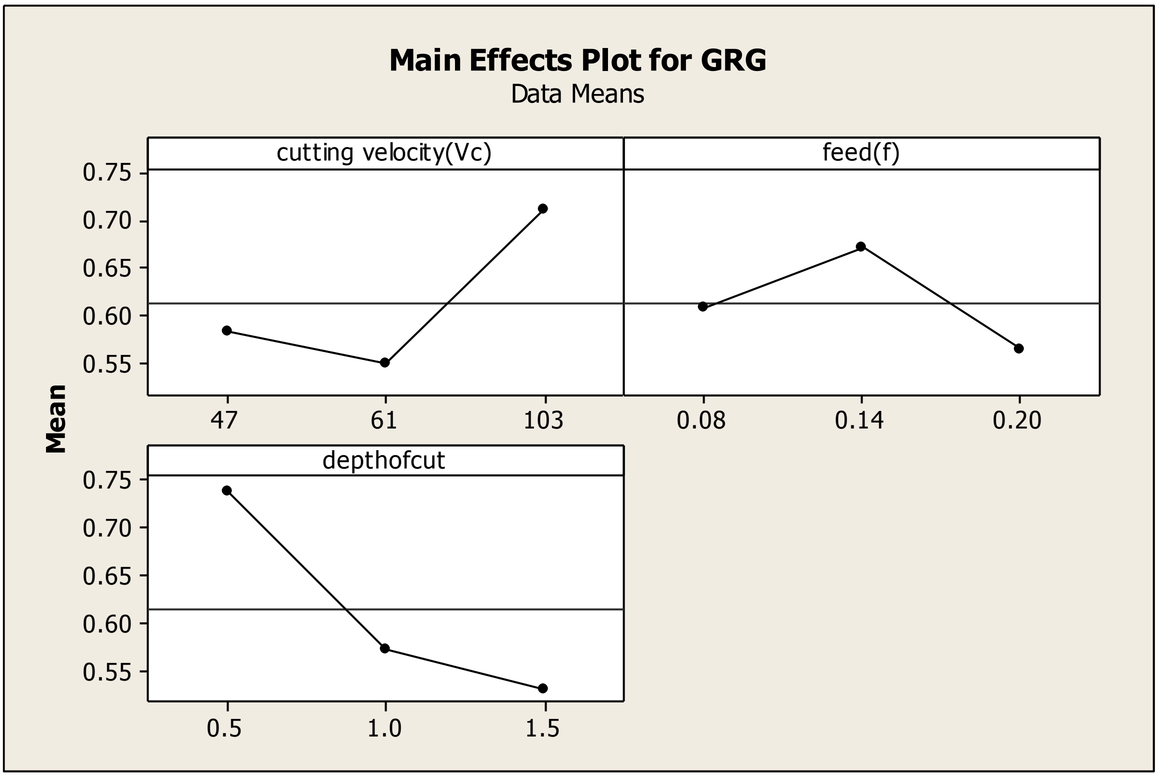


Figure 4.8: Showing mean effect plot of grey relational co-efficient in MQL cutting technique.

From grey relational analysis it is cleared that the highest grey relational grade is obtained for run no.8. Whose V_c = 103m/min, f=0.14mm/rev and t=0.5mm.The output corresponding to this run are F_z = 220, Ra =1.266, $_{friction}$ coefficient (μ) =0.122514.

CHAPTER 5

CONCLUSION

The current research work was carried out to study the comparison of conventional and minimum quantity lubrication during machining of 17-4PH stainless steel. The effect of various cutting parameters (cutting velocity, feed and depth of cut) on different process parameters studied with the help of column graph using Taguchi L9 orthogonal array method. After analysis following conclusions are drawn:

1. From the analysis cutting forces increase with increase in cutting velocity and feed rate. However it was found that there was no significant changes in cutting forces in MQL cooling techniques compare to flood cooling.

2. The surface roughness decrease with increase of depth of cut and cutting velocity. MQL techniques obtained better result with respect to flood cooling.

4. The surface roughness increases in increase of feed rate. In this condition flood cooling system is better compare to MQL lubrication system.

5. Chip reduction co-efficient decrease with increase of cutting velocity and feed rate but increases with depth of cut. When MQL and flood cooling technique are compared MQL gave better result.

6. The optimised process parameters of machining under MQL environment obtained as V=103m/min, f=0.2mm/rev and t=0.5mm.

5.1 Contribution of Research work

The research mainly focused on importance of MQL turning on 17-4PH stainless steel compare to conventional cooling techniques. Hence it is recommended to use MQL for machining purpose of harden stainless steel material used in aerospace industries and other food and chemical processing and oil and petroleum refining equipment. MQL has significant effect on reducing the various output parameter of machining (cutting forces, surface roughness and chip reduction coefficient).

5.2 Recommendation for Future Work

The research indicated that MQL lubricating is the best machining environment to carry out any machining operation on 17-4PH stainless steel. It is the efficient way of cooling the machining process.

Future work on which further research can be done are:

1. Influence of MQL on tool wear characteristics using Taguchi L27 orthogonal array method.

2. Comparative study of and MQL for various process parameters (cutting forces, tool wear and surface roughness etc.). cryogenic cooling

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