Performance Evaluation of MQL on AISI 4130 Steel on Universal Milling Machine

Rupesh M Parthe[1], Taqui Z Quazi[2]

[1] Post graduate scholar, Mechanical Engineering, Saraswati College of Engineering, Kharghar, Mumbai, India

[2] Head, Automobile Engineering Department, Saraswati College of Engineering, Kharghar, Mumbai, India

Abstract: ***Reducing the machining cost is the main aim of every production system. Cost of cooling and lubrication is major contributing factor in the cost of production. Flood type machining possess flow rate up to 20 L/Hr., which uses more amount of cutting fluid. Completely dry machining is not possible because of heat generated in machining. Hence small but appropriate amount of lubrication must be applied. This method is called as near dry machining or Minimum Quantity Lubrication. Work is carried out on universal milling machine using material AISI 4130 alloy steel. Three levels of cutting speed and depth of cut were chosen and respective cutting temperature and surface roughness were recorded for both flood type and MQL technique. Flow rate in MQL is maintained 1.34 L/Hr. Output obtained by experimentation is analyzed on Minitab Software. Using ANOVA, regression analysis, main effect plot and interaction plot conclusion is drawn. There is 93.3% reduction in use of cutting fluid. MQL gives 8.48% reduction in tool temperature, this will improve tool life. MQL produced 19.13% improved surface finish. For this work, cutting fluid applicator (spray gun) is manufactured. Findings of the study show that, MQL appears to be economical and environmentally compatible lubrication technique for sustainable development.***

Keywords: MQL, ANOVA, Regression analysis, Sustainable development

1. Introduction

MQL, also known as “Micro lubrication” and “Near-Dry Machining” is the latest technique of delivering metal cutting fluid to the tool/work interface. Using this technology, a little fluid, when properly selected and applied, can make a substantial difference in how effectively a tool performs. In conventional operations utilizing flood coolant, cutting fluids are selected mainly on the basis of their contributions to cutting performance. In MQL however, secondary characteristics are important. These include their safety properties, environment pollution, human contact, biodegradability, and oxidation and storage stability. This is important because the lubricant must be compatible with the environment and resistant to long term usage caused by low consumption. In MQL, lubrication is obtained via the lubricant, while a minimum cooling action is achieved by the pressurized air that reaches the tool/work interface. Further, MQL reduces induced thermal shock and helps to increase the workpiece surface integrity in situations of high tool pressure.

There are two basic types of MQL delivery systems: external spray and through-tool. The external spray system consists of a coolant tank or reservoir which is connected with tubes fitted with one or more nozzles. Through-tool MQL systems are available in two configurations; based on the method of creating the air-oil mist. The first is the external mixing or one-channel system. Here, the oil and air are mixed externally, and piped through the spindle and tool to the cutting zone.

2. Problem Definition

The flood metal working flood is emulsion of water and oil. The flow rate is typically 20 L/min, delivered to cutting zone at pressure up to 70 bar. Flood metal working fluid system requires significant plant infrastructure for delivery, reclamation, filtration, chilling and waste water treatment. Furthermore system demands constant monitoring and treatment to control fluid concentration and to avoid fungal and bacterial growth. To address these issues, there has been steadily increasing interest in performing machining operations dry or near dry. Dry machining can totally avoid the use of cutting fluids, and it requires less power to be accomplished. On the other hand side, friction and cutting temperatures could be higher than that of wet machining. This reduces tool life and may cause thermally-induced geometrical deviations in the machined part. Hence there is need of near dry machining called minimum quantity lubrication. MQL is environment friendly. These systems supply fluids in small amount, in the form of precision metered droplets, under the support of compressed air, Vegetable oils are generally used for MQL, due to their high biodegradability and emulsions or water can be applied for MQL systems.

3. Methodology

For experimentation Diamond Engineering make MM/114 universal horizontal milling machine is used. These versatile milling machines, not only possess both horizontal milling arbor and the vertical axis spindle, the latter spindle can be further tilted about one (X) or both the horizontal axes (X and Y) enabling machining jobs of complex shape.

AISI 4130 alloy steel is selected for experimentation. ASTM A519/AISI Grade 4130 is alloy steel grade with Carbon 0.28 to 0.33%, Silicon 0.15 to 0.35%, Sulfur 0.04% max, Phosphorus 0.04% max, Manganese 0.40 to 0.60%, Chrome 0.80 to 1.10%, Molybdenum 0.15 to 0.25%. 4130 contents alloy elements chromium and molybdenum which is the reason it is also called as chromoly.

3.1 Parameters

Table 1: Input Parameters

Parameters	*Levels*
Cutting speed	65, 100, 145 (rpm)
Depth of cut	1, 2, 3 (mm)
Cutting fluid conditions	Flood, MQL

Cutting Temperature and Surface roughness are selected as output parameters.

3.2 Experiment Procedure

1 Mount workpiece on machine
2 Select cutting speed
3 Select depth of cut
4 Adjust the fluid flow as required
5 Start the pressurized air to flow through applicator
6 Start machining
7 Note down temperature by thermocouple
8 Unmount workpiece and measure surface roughness
9 Repeat the same process with flooded flow type machining.

Figure 1: Experimental Setup

Figure 2: Workpiece after machining

4. Result Analysis

Experimentation is done and respective cutting temperature and surface roughness is recorded in observation table. Results are analyzed on Minitab software.

4.1 Relation between cutting temperature and input parameters

Main effect plot shows linear relationship on the variation in cutting temperature produced during milling operation. It is observed from main effect plot generated using MINITAB that depth of cut has higher contribution to the variability of cutting temperature over the other experimental factors. There is considerable reduction in the cutting temperature during MQL.

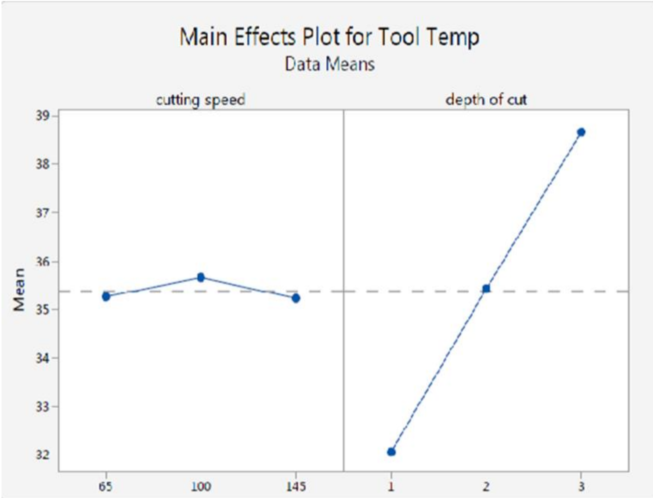

Figure 3: Main effect plot for cutting temperature

For general linear model of ANOVA, F-value for depth of cut is 780.99 ($p<0.0001$). Hence it most significant parameter. In MQL, minimum cutting fluid is mixed with air at high pressure of 5 bar. Mixing of air in cutting fluid reduces the cutting temperature. Significantly MQL facilitates both convective and evaporative heat transfer leads to lowering of cutting temperature.

Table 2: Analysis of variance for tool temperature

Source	*DF*	*Adj. SS*	*Adj. MS*	*F-Value*	*P-Value*
Regression	2	65.3469	32.6735	390.54	<0.0001
Cutting Speed	1	0.0069	0.0069	0.08	0.7835
Depth of cut	1	65.3400	65.3400	780.99	<0.0001
Error	6	0.5020	0.0837		
Total	8	65.8489			

Multiple regression analysis is performed to demonstrate the fitness of the experimental measurement. The regression is simulated using MINITAB software.

Tool Temp = 28.8763-0.000846×Cutting Speed+3.3×Depth of cut

For Example assume cutting speed=100 rpm and depth of cut=2 mm.

Tool Temp = 28.8763 - 0.000846×100 + 3.3×2

Tool Temp = 35.3917^{0}C

This is theoretical value of tool temperature and practical value of tool temperature when cutting speed is 100 rpm and depth of cut is 2mm is 35.6^{0}C. Experimental and analytical values are nearly equal with error of 0.5 %. Hence results are valid.

4.2 Relation between surface roughness and input parameters

Ra value is noted down in observation table, main effect plot of these Ra values is plotted against cutting speed and depth of cut. When cutting speed changes from 65 to 100 rpm, there is increase in roughness but when speed changes from 100 to 145 rpm, there is decrease in roughness value. Hence, Ra value is not proportionate with cutting speed. But depth of cut is directly proportional to Ra value. Hence depth of cut is significant factor in surface finish obtained by milling operation.

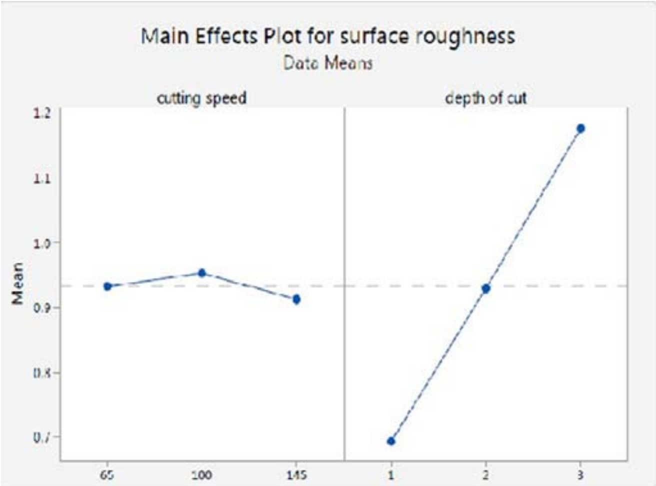

Figure 4: Main effect plot for surface roughness

For general linear model of ANOVA, F-value for depth of cut is 44.33 which is maximum. Hence it is most significant parameter. Surface finish depends upon the feed rate of the tool with respect to work piece and supply of cutting fluid. As depth of cut increases poor surface finish occurs.

Table 3: Analysis of variance for Surface roughness

Source	*DF*	*Adj. SS*	*Adj. MS*	*F-Value*	*P-Value*
Regression	2	0.351172	0.175586	22.21	0.0017
Cutting Speed	1	0.000755	0.000755	0.10	0.7677
Depth of cut	1	0.350417	0.350417	44.33	0.0006
Error	6	0.047428	0.007905		
Total	8	0.398600			

Multiple regression analysis is performed to demonstrate the fitness of the experimental measurement. The regression is simulated using MINITAB software.

Surface Roughness = 0.4789 – 0.0002798×cutting speed + 0.24167×depth of cut

For example, assume cutting speed is 145 rpm and depth of cut is 3 mm.

Surface Roughness = 0.4789 – 0.0002798×145 + 0.24167×3
Surface Roughness = 1.163 µm

This is the analytical value of surface roughness (Ra). The practical value is 1.21µm. The experimental and practical values are nearly equal with error 3%. Hence these results are also valid.

4.2 Comparative Assessment

Table 4: Comparison between MQL

Response Variable	*Flood type m/c*	*MQL*	*Diff*	*Change (%)*
Tool Temperature	38.6 ^{0}C	35.38 ^{0}C	3.28	8.48%
Surface Roughness	1.15 µm	0.93 µm	0.22	19.13%
Flow rate	20 L/hr.	1.34L/hr	18.66	93.3%

Above table clearly shows that average of tool temperature in flood type machining is 38^{0}Cand in MQL is 35.38^{0}C. There is 8.48% reduction in temperature. Average Ra value in flood type machining is 1.15 µm and in MQL is 0.93 µm. There is 19.13% improvement in surface finish. In flood type machining flow rate is 20L/hr. and in MQL which is 1.34 l/hr. There is substantial reduction up to 93.3% in the use of cutting fluid. This huge reduction in use of cutting fluid will reflect in cost of procurement, cost of storage and mainly cost of disposal. Hence cost of production will be minimized with use of only 6.7% of cutting fluid.

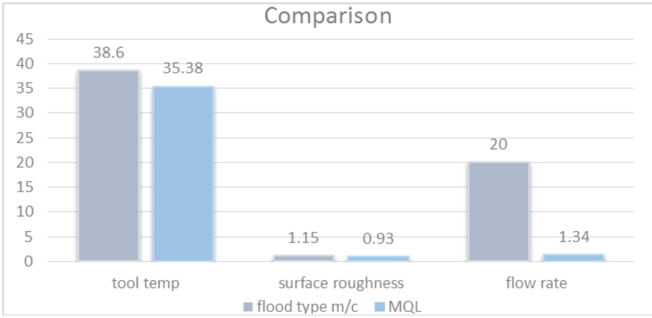

Figure 5: Comparison between MQL and Flood type

5. Conclusion

Cutting fluids have more impact on cost of production and environment. MQL use minute amount of cutting fluid this lead to minimized cost of production. In flood type machining large amount of cutting fluid add the cost of purchase, storage and disposal. Large amount disposal affects the environment. Work is carried out on universal milling machine on material alloy steel AISI 4130. And different parameters are analyzed. Results shows that MQL system is much better that traditional method. Improvement in parameters like cutting temperature and surface finish is observed in MQL.

1) There is 93.3% reduction in the use of cutting fluid
2) MQL gives 8.48% reduction in tool temperature. This will improve the tool life.
3) Surface finish in milling of AISI 4130 is better in MQL. It gives 19.13% improvement in surface finish
4) ANOVA concludes that, depth of cut is most significant factor in milling operation.

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