**Optimization of Minimum Quantity Lubrication Parameters**

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**Abstract:** Cutting fluids are inevitable in manufacturing industries due to their cooling and lubricating properties. But their applications in large quantities pose serious threat to biological bodies in the oceans and rivers when disposed untreated. Strict rules and fines imposed by most of the countries on such industries, created an economic and environmental concern. This led to research in finding alternative methods to either eliminate or reduce the usage of cutting fluids. Minimum quantity lubrication (MQL) is one of such methods being widely tested to replace flood machining. Application of cutting fluid as MQL requires decision of choosing the optimum MQL parameters. The present paper deals with optimizing the MQL system parameters used to minimize cutting forces and surface roughness.

***Keywords:*** Minimum Quantity Lubrication, Air metering screw, Cutting forces, Surface roughness

**1. Introduction**

Almost all manufacturing industries involve a section containing machine tools used for metal cutting operations. In order to increase the tool life and to reduce the cost of machining, cutting fluids are applied in large quantities as flood machining. Disposal of untreated used cutting fluids to water bodies like rivers and oceans pose serious threat to biological bodies. Strict rules and fines are imposed by most of the countries on such industries. This created economic and environmental concern, which led to research in finding alternative methods to either eliminate or reduce the usage of cutting fluids[1]. Minimum quantity lubrication (MQL) is one of such methods being widely tested to replace flood machining. Most of the researchers applied MQL to machining and found it to be effective over dry and flood machining [2- 5]. Few of the researchers performed machining using nanofluids, which are applied as MQL during machining [6-10]. MQL systems may be classified as MQL with external supply and MQL with internal supply. In the former case, cutting fluid is supplied externally, while in later case, cutting fluid is supplied through the tool. MQL can be externally supplied in two ways as shown in Fig 1. MQL – 1, where cutting fluid along with compressed air is supplied to a nozzle and aerosol is formed just after the nozzle and MQL- 2, where aerosol is prepared separately in a closed chamber and is supplied to the cutting zone using conventional nozzle. Before application of cutting fluid as MQL to any machining, a proper study of all the process parameters has to be carried out, to understand its influence in machining responses. The present work deals with study of effect of process parameters of MQL Unist Coolubricator on cutting forces and surface roughness while machining AISI1040 steel.

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| **Fig 1: External MQL supply [1]** | **Fig 2: Unist Coolubricator** |

**2. Experimentation**

Machining is performed on widely used medium carbon steel AISI1040 at constant cutting parameters: Cutting speed of 560rpm, feed: 0.15mm/rev, depth of cut: 0.5mm. Unist coolubricator shown in Fig 2 is used to apply conventional cutting fluid as Minimum Quantity Lubrication. It consists of different parts like air filter, solenoid valve, positive displacement metering pump which precisely supplies cutting fluid at 0.03ml/stroke, pneumatic pulse generator which controls the pump cycle rate (pulses/min), air metering screw which controls the supply of air, pump stroke adjustment to control the quantity of coolant / lubricant and fluid reservoir to store cutting fluid. Of all the parts, three main MQL system parameters are air pressure; air quantity, which is controlled by air metering screw and lubricant / coolant quantity, which is controlled by pulse generator. Air quantity is varied by adjusting the air metering screw to half turn, three fourth turn and full turn, which changes the outlet cross section area of air nozzle from 2mm2 to 4mm2 to 6mm2. Quantity of lubricant is varied by adjusting the pulse generator to 10, 20, 40 which supplies lubricant at rate 0.3ml/min,0.6ml/min and 1.2 ml/min respectively. Levels and parameters considered are shown in Table 1. Taguchi L9 experiments are conducted. Each experiment is conducted thrice. Nozzle is placed such that cutting fluid is applied at the back of the chip. Cutting forces are measured using Kistler dynamometer and their resultant is used for further analysis. Surface roughness is measured using Mitutoyo Surftest301J.

**Table 1: Levels and parameters considered**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Level 1** | **Level 2** | **Level 3** |
| **Air Pressure (psi) (A)** | 70 | 75 | 80 |
| **Cross section area of nozzle (mm2) (B)** | 2 | 4 | 6 |
| **Coolant flow rate(ml/min) (C)** | 0.3 | 0.6 | 1.2 |

**3. Results and Discussions:**

Table 2 shows the input parameters and responses i.e cutting forces and surface roughness with all experiments. Fig 3 shows the main effect plots for resultant cutting force and surface roughness. Table 3 shows the response table for cutting forces as well as surface roughness.

**Table 2: Input parameters and responses for all experiments**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Expt No.** | **Air Pressure (psi)**  **(A)** | **Cross section area of nozzle (mm2) (B)** | **Coolant flow rate (ml/min) (C)** | **Resultant Cutting Force**  **(N)** | | | **Surface Roughness (µm)** | | |
| 1 | 70 | 2 | 0.3 | 409.13 | 400.23 | 410.34 | 4.93 | 5.01 | 4.86 |
| 2 | 70 | 4 | 0.6 | 384.56 | 375.58 | 386.84 | 3.75 | 3.87 | 3.64 |
| 3 | 70 | 6 | 1.2 | 308.34 | 306.43 | 305.34 | 3.90 | 3.91 | 3.9 |
| 4 | 75 | 2 | 0.6 | 364.34 | 366.04 | 368.36 | 3.88 | 4.31 | 3.46 |
| 5 | 75 | 4 | 1.2 | 256.84 | 260.23 | 253.34 | 3.48 | 3.7 | 3.26 |
| 6 | 75 | 6 | 0.3 | 265.34 | 271.28 | 268.15 | 3.32 | 3.51 | 3.13 |
| 7 | 80 | 2 | 1.2 | 219.47 | 221.24 | 216.49 | 3.89 | 4.46 | 3.32 |
| 8 | 80 | 4 | 0.3 | 605.32 | 606.51 | 600.23 | 3.27 | 3.37 | 3.18 |
| 9 | 80 | 6 | 0.6 | 336.20 | 324.57 | 341.23 | 3.34 | 3.27 | 3.41 |

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| **(b)**  **Fig 3: Main effect plot for (a) Resultant cutting force (b) Surface roughness** |

**Table 3:**

|  |  |
| --- | --- |
| 1. **Response Table for Cutting forces** | 1. **Response Table for Surface roughness** |
| |  |  |  |  | | --- | --- | --- | --- | | **Level** | **Air Pressure (psi)**  **(A)** | **Cross section area of nozzle (mm2) (B)** | **Coolant flow rate (ml/min) (C)** | | 1 | 365.2 | 330.6 | 426.3 | | 2 | 297.1 | 414.4 | 360.9 | | 3 | 385.7 | 303.0 | 260.9 | | Delta | 88.6 | 111.4 | 165.4 | |  | 3 | 2 | 1 | | |  |  |  |  | | --- | --- | --- | --- | | **Level** | **Air Pressure (psi)**  **(A)** | **Cross section area of nozzle (mm2) (B)** | **Coolant flow rate (ml/min) (C)** | | 1 | 4.198 | 4.237 | 3.843 | | 2 | 3.562 | 3.503 | 3.660 | | 3 | 3.502 | 3.522 | 3.758 | | Delta | 0.697 | 0.733 | 0.183 | |  | 2 | 1 | 3 | |

Main effect plot for resultant cutting forces shows that with increase in air pressure, cutting forces decreased and then increased. Increase in air pressure from 70 psi to 75psi may have caused effective entry of cutting fluid to the cutting zone, leading to better lubrication and hence decrease in cutting forces. Further increase in air pressure reduces the quantity of lubricant and hence led to increase in cutting forces. Increase in air pressure, may have increased the spray angle, leading to reduced entry of coolant in the cutting zone.

**Table 4:**

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| --- |
| 1. **ANOVA for cutting forces** |
| |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | **Source** | **DF** | **SeqSS** | **AdjSS** | **AdjMS** | **F** | **p** | **% contribution** | | A | 2 | 38718 | 38718 | 19359 | 4.44 | 0.025 | 12.43 | | B | 2 | 60565 | 60565 | 30282 | 6.95 | 0.005 | 19.45 | | C | 2 | 124937 | 124937 | 62468 | 14.33 | 0.000 | 40.12 | | Error | 20 | 87164 | 87164 | 4358 |  |  |  | | Total | 26 | 311383 |  |  |  |  |  | |
| 1. **ANOVA for Surface roughness**  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | **Source** | **DF** | **SeqSS** | **AdjSS** | **AdjMS** | **F** | **p** | **% contribution** | | A | 2 | 2.68287 | 2.68287 | 1.34143 | 16.60 | 0.000 | 35.3 | | B | 2 | 3.14802 | 3.14802 | 1.57401 | 19.48 | 0.000 | 41.4 | | C | 2 | 0.15152 | 0.15152 | 0.07576 | 0.94 | 0.408 | 1.99 | | Error | 20 | 1.61572 | 1.61572 | 0.08079 |  |  |  | | Total | 26 | 7.59812 |  |  |  |  |  | |

Increase in pulse generator, led to more strokes/min, which increased the coolant flow rate. More quantity of coolant may have caused better lubrication leading to decrease in cutting force. Response table 3 (a) for cutting forces shows that coolant flow rate influences cutting forces the most followed by cross section area of nozzle. Main effect plots for surface roughness shows that with increase in air pressure, surface roughness has reduced. Increase in air pressure led to easier evacuation of chips from the cutting zone, preventing them from rubbing against the workpiece, leading to better surface finish. With increase in area of cross section of nozzle from 2 to 4 mm2, quantity of air supplied increased, leading to better mist formation. This might have lead to better lubrication in cutting zone leading to improved surface finish. With further increase in opening of cross section of nozzle from 4 to 6 mm2, surface finish remained stable showing no further increase in lubrication**.** Variation in coolant flow rate does not have much influence on surface roughness, as the inclination of the line is less. This can also be seen from response table 3 (b) which shows that area of cross section of nozzle highly influenced surface roughness followed by air pressure. Table 4 shows the ANOVA table for cutting forces and surface roughness. ANOVA table for cutting forces show that factor C i.e coolant flow rate contributes for cutting forces the most, followed by factor B i.e cross section area of nozzle. This is inline with the conclusion drawn from response table 3(a). ANOVA table for surface roughness show that factor B i.e cross section area of nozzle contributes for surface roughness the most, followed by factor A i.e air pressure. This is inline with the conclusion drawn from response table 3(b). Fig 3a shows that optimal MQL parameters which minimize cutting forces are A2B3C3 and A3B2C2 minimizes surface roughness.

Conclusions:

1. Coolant flow rate contributes the most followed by cross section area of nozzle to cutting forces generated during machining AISI1040.
2. Air metering screw, which controls the cross section area of nozzle and hence the quantity of air supplied, contributes the most followed by air pressure to surface roughness generated during machining AISI1040.
3. Optimum MQL parameters which minimize cutting forces are A2B3C3 i.e air pressure of 75psi, nozzle cross section area of 6mm2 and coolant flow rate of 1.2ml/min.
4. Optimum MQL parameters which minimize surface roughness are A3B2C2 i.e air pressure of 80psi, nozzle cross section area of 4mm2 and coolant flow rate of 0.6ml/min.

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