Evaluation of the performance during hard turning of OHNS steel with minimal cutting fluid application and its comparison with minimum quantity lubrication

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Abstract. Cutting fluid application plays a significant role in the manufacturing industries that acts as a coolant as well as a lubricant. The conventional flood cooling application of cutting fluids not only increases the production cost on account of the expenses involved in procurement, storage and disposal but also creates serious environmental and health hazards. In order to overcome these negative effects, techniques like Minimum quantity lubrication (MQL) and Minimal Cutting fluid application (MCFA) have increasingly found their way into the area of metal cutting and have already been established as an alternative to conventional wet machining. This paper investigates the effect of minimal Cutting fluid application (MCFA) which involves application of high velocity pulsing jet of proprietary cutting fluids at the contact zones using a special fluid application system. During hard turning of oil hardened non shrinkable steel (OHNS) on cutting temperature and tool wear and to compare the performance with Minimum quantity lubrication (MQL) assisted hard turning in which cutting fluid is carried in a high velocity stream of air. An attempt was also made to compare the performance during Turning with MCFA and MQL application with conventional wet and dry turning by analysing the tool wear pattern using SEM images.

Keywords—Minimal quantity lubrication, Minimal cutting fluid application, Dry turning, Scanning electron Microscope.

1. Introduction

Machine Parts that require high hardness as for functioning are usually machined in the soft state, then hardened to the required hardness and finish ground to the final dimensional requirements. This time consuming and cost inculcating process can be reduced if the hardened components in the near net shape can be turned in to the final dimension. Hard turning is performed on materials with hardness within the range of 35–68 HRc using a variety of tipped or solid cutting inserts. During metal removal operations, the important problems faced are increase in temperature and tool wear. These are caused by the normal load generated by the interaction between tool and workpiece and by the relative motion between tool and chip. Tool wear, is considered one of the most important economic penalties to be taken into consideration during cutting. So it is very important to improve tool life by minimizing the wear and cutting temperature. Hard turning is carried out in accompaniment with copious supply of cutting fluid which acts as a coolant as well as a lubricant.

Cutting fluid usage in very large quantities degrade the shop floor environment by increasing oil mist content in the air. According to regulations recommended by occupational safety and health administration (OSHA) the oil mist content in the air should be less than 0.5 gm/m³ of air. A study conducted at the metal working industries in Europe revealed that there is an approximate usage of 32000 tons of cutting fluids every year. The study also disclosed that at least two thirds of this cutting fluid need to be disposed [1]. Implementation of dry machining will help to avoid problems associated
with the usage of cutting fluids. It is very difficult to implement dry machining on the existing shop floor, as it needs extremely rigid machine tools and ultra-hard cutting tools [12]. In order to ease the above-mentioned undesirable effects of cutting fluids, machining with minimal cutting fluid application (MCFA) have been developed. Minimal cutting fluid application and Minimum quantity lubrication (MQL) can promote a green environment in the shop floor, by minimizing the usage of large quantity of cutting fluid. Minimum quantity lubrication (MQL) and minimal cutting fluid application (MCFA) are considered as lubricating technologies that are safe, environmentally friendly, and makes production more efficient. MQL could provide good lubrication if the appropriate lubricant is used. As reported by some authors, metal-working fluid cost ranges from 7 to 17% of the total machining cost, while the tool cost ranges from 2 to 4%. Dhar et al. [4] employed MQL technique in turning of AISI 1040 steel and the results clearly indicated that a mixture of air and cutting fluid in machining is better than a conventional flood cooling system. Using MQL technique is a remarkable alternative in reducing machining costs. MQL produces a lot of oil mist in the shop floor environment, which creates problems in terms of both employee’s health and environmental pollution. This problem is almost absent in Minimal cutting fluid application (MCFA). Use of minimum quantity lubrication system (MQL) and minimal cutting fluid application (MCFA) plays an important role in respect of the achievable dimensional accuracy and the level of environmental pollution and health hazard to the employee.

During minimal fluid application, the cutting fluid is applied at the tool–chip and tool-work interface. Cutting fluid applied at high pressure and velocity helps the tiny fluid particles to penetrate the work surface near the cutting edge that forms the top of the chip in the next revolution. These particles, owing to their high velocity and smaller physical size can penetrate and firmly adhere to the work surface resulting in the promotion of plastic flow on the backside of the chip due to Rebinder effect. This phenomenon, in turn, helps in reducing the tool-chip contact length which in turn reduces the main cutting force and the cutting temperature [9]. The Minimum quantity lubrication (MQL) and Minimal cutting fluid application (MCFA) are found to be more effective lubrication systems compared to conventional lubrication [12] However, still Minimal cutting fluid application (MCFA) was found to be more effective as compared Minimum quantity lubrication (MQL), wet and flood cooling techniques. The present work aims at comparing the performance during turning with Minimal cutting fluid application (MQL) with that during Minimal Cutting fluid application (MCFA).

2. Experimentation

2.1 Selection of work material

OHNS steel rod of 350 mm length and 75 mm diameter with a hardness of 45 HRc was selected as the work material for this investigation. This grade of steel has got a wide range of application in tool and die making industries. It is well known for its high tensile strength and toughness. Tool inserts SNMG 120408 along with a tool holder with a specification PSBNR 2525 M12 as recommended by M/s TaeguTec India (P) Ltd were used for the present investigation.

| Table 1. Composition of work piece material |
|-------------------------------------------|
| Carbon | Chromium | Tungsten | Vanadium |
| 0.95   | 0.5      | 0.6      | 0.15     |

2.2 Design of experiments.

A nine run, three factors, three level orthogonal array was designed by following Taguchi’s design of experiments to perform the experiments which is shown in Table 2.
Table 2. Design matrix for nine-run, three-level experiment with three factors

| SNo | Factorial Combination | Cutting Speed(n) | Feed Rate(f) | Depth Of Cut(d) |
|-----|----------------------|------------------|--------------|----------------|
| 1   |                      | 1                | 1            | 1              |
| 2   |                      | 1                | 2            | 2              |
| 3   |                      | 1                | 3            | 3              |
| 4   |                      | 2                | 1            | 2              |
| 5   |                      | 2                | 2            | 3              |
| 6   |                      | 2                | 3            | 1              |
| 7   |                      | 3                | 1            | 3              |
| 8   |                      | 3                | 2            | 1              |
| 9   |                      | 3                | 3            | 2              |

2.3 Selection of cutting parameters

The levels of cutting parameters were selected based on the earlier work reported in this area [6]. Table 3 shows the selected cutting parameters and their levels.

Table 3. Levels of cutting parameters

| Input process parameters | Level 1 | Level 2 | Level 3 |
|--------------------------|---------|---------|---------|
| cutting speed (m/min)    | 75      | 95      | 115     |
| feed rate (mm/rev)       | 0.05    | 0.075   | 1       |
| Depth of cut (mm)        | 0.5     | 0.75    | 1       |

2.4 Experimental setup

Figure 1 shows the experimental set up for MQL assisted hard turning in which a pneumatic MQL spray gun is filled and the cutting fluid is propelled by compressed air. The MQL setup was developed in house at Karunya University. It consists of a spray gun, air cap, fluid nozzle, and a compressor which supplies a stream of high velocity air that propels the tiny droplets of oil coming out of the nozzle to the cutting zone. The rate of flow of oil was maintained as 8ml/min and the pressure at the compressor was kept at 10 bar.

Figure 1. Experimental set up for MQL assisted hard turning
(A. MQL apparatus, B. Dynamometer setup)
Figure 2 shows the experimental set up for MCFA assisted hard turning which was also developed in house at Karunya University [14]. It consists of a P-4 fuel pump (Bosch make) coupled to an infinitely variable electric drive. The fluid applicator employed has injector nozzles of single hole type with a specification DN0SD151 with a spray angle of 0°.

Two such nozzles were employed to apply a high velocity pulsing jet of cutting fluid at the tool-work and the tool-chip interfaces. Cutting temperature was considered as an output parameter and it was measured using an optical pyrometer. The pressure at the fluid injector was maintained at 100 bar, the frequency of pulsing as 600 pulses/min, the composition of cutting fluid as 20% oil in water and the rate of application of cutting fluid as 8 ml/min.

| S No | Cutting Speed (m/min) | Feed Rate (mm/rev) | Depth of cut (mm) | Cutting Temperature during MQL application | Cutting Temperature during MCFA |
|------|-----------------------|--------------------|-------------------|--------------------------------------------|---------------------------------|
|      |                       |                    |                   | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| 1    | 75                    | 0.05               | 0.5               | 107.6   | 96.4   | 83.1    | 74.42   |
| 2    | 75                    | 0.075              | 0.75              | 112.1   | 127.9  | 86.1    | 100.2   |
| 3    | 75                    | 0.1                | 1                 | 157.2   | 138.1  | 127.8   | 108.19  |
| 4    | 95                    | 0.05               | 0.75              | 108.3   | 121.2  | 85.23   | 98.61   |
| 5    | 95                    | 0.075              | 1                 | 157.23  | 140.56 | 126.23  | 114.63  |
| 6    | 95                    | 0.1                | 0.5               | 118.1   | 141.4  | 92      | 114.63  |
| 7    | 115                   | 0.05               | 1                 | 142.1   | 125.01 | 115     | 98.43   |
| 8    | 115                   | 0.075              | 0.5               | 124.7   | 155.13 | 96      | 127.3   |
| 9    | 115                   | 0.1                | 0.75              | 161.3   | 138.7  | 131     | 108.7   |

3. Results & discussions

3.1 ANOVA analysis
Statistical analysis of the experimental results was carried out using the analysis of variance (ANOVA). ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. The ANOVA analysis was carried out to establish the effect of individual parameters on cutting temperature with MQL and MCFA assisted hard turning and the results are shown in Table 5 and Table 6. From the ANOVA results, it was found that all the F values for all the input parameters against cutting temperature is greater than 2 (F>2) and thus the results are valid. From Table 5 we see that feed rate is the most significant factor with 41% and 42% in both the systems followed by depth of cut with 24% and 23% and cutting speed with 18% and 21% in MQL and MCFA respectively. Figure 3 shows the comparison of temperatures measured during hard turning of OHNS steel with MQL and MCFA. It is observed that the average cutting temperature during hard turning with Minimal Fluid Application was less than that during MQL.

**Figure 3.** Comparison of the cutting temperature during hard turning with MQL & MCFA.

**Table 5.** Analysis of variance of Cutting Temperature during MQL assisted hard turning

| Col# Factor       | DOF (f) | Sum of Sqr. (S) | Variance (V) | F-Ratio (F) | Pure Sum (S') | Sum | Percent (%) |
|-------------------|---------|-----------------|--------------|-------------|---------------|-----|-------------|
| Cutting speed [m/min] | 2       | 505.547         | 252.773      | 6.249       | 424.658       | 18.472 |
| Feed rate [mm/rev]  | 2       | 1064.226        | 532.113      | 13.156      | 983.338       | 42.774 |
| Depth of cut [mm]   | 2       | 648.226         | 324.113      | 8.013       | 567.338       | 24.678 |
| Error              | 2       | 80.887          | 40.443       | 14.076      |               | 14.076 |
| Total              | 8       | 2298.888        |              | 100.00%     |               | 100.00% |
Table 6. Analysis of variance of Cutting Temperature during MCFA assisted hard turning

| Col#/ Factor         | DOF  | Sum of Sqr. (S) | Variance (V) | F-Ratio (F) | Pure Sum (S') | Sum | Percent (%) |
|----------------------|------|-----------------|--------------|-------------|---------------|-----|-------------|
| Cutting speed [m/min]| 2    | 416.89          | 208.445      | 7.243       | 359.334       | 21.318 |              |
| Feed rate [mm/rev]  | 2    | 750.89          | 375.445      | 13.046      | 693.334       | 41.133 |              |
| Depth of cut [mm]   | 2    | 460.218         | 230.109      | 7.996       | 402.662       | 23.889 |              |
| Error               | 2    | 57.555          | 28.777       |             |               | 13.66  |              |
| Total               | 8    | 1685.555        |              |             |               | 100.00% |              |

3.2 Analysis of flank Wear

During wet turning (Fig. 4) the flank wear was comparably lower than that during dry turning (Fig. 5). Fig. 6 shows the flank wear occurred during MQL assisted hard turning. In this case flank wear was very much lower compared to wet and dry hard turning. It is seen that the flank wear was minimum during MCFA assisted hard turning. The images was captured using a Scanning electron microscope at 100x magnification factor. The flank wear was measured with the help of IMAGEJ software. This software helps to mark and measure wear affected area. Tool wear was measured at different sections of the tool and average value was taken in each case. The summarized tool wear values are given in table 7. It was observed that the flank wear was minimum during hard turning with minimal fluid application (MCFA) followed by hard turning with MQL. Fig. 4 to Fig. 7 shows SEM images of average flank wear during wet, dry, MQL, MCFA assisted hard turning. The flank wear was maximum in dry turning.

![Figure 4. SEM image of tool flank wear during wet hard turning (Cutting velocity= 75 m/min, Feed= 0.05 mm/rev, depth of cut = 0.5 mm)](image-url)
Figure 5. SEM image of tool flank wear during dry turning (Cutting velocity= 75 m/min, Feed= 0.05 mm/rev, depth of cut = 0.5 mm).

Figure 6. SEM image of tool flank wear during MQL assisted hard turning (Cutting velocity= 75 m/min, Feed= 0.05 mm/rev, depth of cut = 0.5 mm).

Figure 7. SEM image of tool flank wear during MCFA assisted hard turning (Cutting velocity= 75 m/min, Feed= 0.05 mm/rev, depth of cut = 0.5 mm).
Table 7. Tool wear measured by IMAGEJ software

| SNo | Cutting Speed (m/min) | Feed Rate (mm/rev) | Depth of cut (mm) | Dry turning (µm) | Wet turning (µm) | MQL turning(µm) | MCFA turning(µm) |
|-----|----------------------|--------------------|------------------|-----------------|-----------------|----------------|-----------------|
| 1.  | 75                   | 0.05               | 0.5              | 0.08            | 0.05            | 0.034          | 0.018           |

4. Conclusion.

The experimental investigations led to the following conclusions,

- It was found that there was a 23.52% reduction in cutting temperature during MCFA assisted hard turning when compared to MQL assisted hard turning.
- The overall performance during Minimal Cutting Fluid Application was found to be superior to that during dry turning, conventional wet turning and hard turning with MQL on the basis of tool wear.
- This technique can form a viable alternative to conventional wet turning and MQL assisted hard turning as it is more environment friendly and technologically superior to the MQL assisted hard turning and can be implemented on the shop floor without drastic alterations in the existing setups.

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