ASSESSMENT OF MACHINING PARAMETERS ON EN-24 STEEL UNDER DRY, WET AND MQL CONDITION USING MULTI COATED INSERTS

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Abstract: The minimum quantity lubrication is an interesting possibility for an economical and environmentally compatible production, which unifies the functionality of coolants and lubricants with mightily less consumption of lubricants. In this experiment, minimum quantity lubrication setup on turning machine was design and developed for comparison between dry and wet conditions and their effects are considered under different parameters. This setup uses mist/flood formation of lubricants with the help of minimum quantity lubrication. This strategy is used to improve machining of the product surface quality during turning operation. The surface roughness value has been taken as an output response; the surface roughness value of the machined part was evaluated using Talysurf surface roughness tester. The design of experiment was enacted on Taguchi’s orthogonal array L\textsuperscript{9} to optimize the selected process parameters during turning of EN-24 under different conditions. The Grey relational method was also applied for optimizing purposes. The optimum conditions include a cut 0.6 mm deep, a nose radius of 0.8mm and a cutting speed of 575 rpm and the depth of cut was found out to be most dominant parameter. MQL shows better results in terms of surface roughness as compared to dry and wet conditions.

Keywords: En-24 Material, MQL (Minimum quantity Lubrication), Surface Roughness, Taguchi method, Grey relation method

1. INTRODUCTION

Nowadays, the manufacturing industries are focused not just on increasing the productivity but, also on improving the quality of the product. The effect of cutting fluids plays an effective role on worker health, working environment and enhancing the productivity of machining like turning operation, milling operation, drilling operation and others. For cooling and lubrication purposes of the work-piece and enhancing tool life; wet machining is most commonly used in industries, Çakır et al., (2016). In his investigation, he found that for the surface roughness value main dominant parameter is feed and the impact of flow rate on the surface quality was more as compared to the feed rate. Zhang et al., (2015), in his study while using MQL concept with nanoparticles in grinding operation found, that palm oil has lower coefficient of friction as compared to liquid paraffin and it also reduces the specific grinding energy. Ekinovic et al., (2015) concluded that by using MQL phenomena, the reduction in the cutting temperature and improved tool life make an important change which were improves due to the reduction in chip–tool interaction. It has also been defined; that, better surface finish was achieved as compared to dry and wet machining of steel. It was caused due to reduction of wear and damage of the tool tip by applying the MQL setup. Singh et al., (2013), used this technique of heat reduction, which was accomplished by continuous flow of cutting fluid, the result of surface roughness was obtained by using vegetable oil, and the surface roughness value got reduced by 20-40% as compared to dry machining. Hadad et al., (2013) studied that the influence of nozzle position plays and effective role on effectiveness of the cutting parameters on turning operation

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in terms of quality of the product produce because it impacted the output parameter such as machining forces, surface roughness value and cutting temperature. Hwang et al., (2010) concluded that the surface roughness value and cutting force using MQL turning operation provide better result than using wet lubrication under turning operation. Sharma et al., (2009) in his experiment while using MQL technique, an amazing reduction in quantity of lubricant used during the process, major change in the surface roughness value has been achieved by properly orienting the nozzle on flank face of the tool and work interface. Kamata et al., (2007) found that the most promising results are achieved by minimum quantity lubrication concept in both tool life and surface roughness value, which has been performed under turning operation at high speed. Dhar et al., (2006) used MQL technique for turning operation on work material AISI 1040 steel in his experiment and found that the result of MQL machining is better than a conventional flood coolant system. His experiment also showed a tremendous reduce in cutting temperature which also improved the sharpness of the cutting edges. Jhon et al., (2016) optimized it with the help of RSM technique on EN 9 hardened steel. The optimum surface roughness and its surface hardness are 0.2 µm and 18 HRC, respectively. The surface roughness is reduced by 94.5% and hardness is improved by 41.7%.

Work piece material: In this study, EN-24 steel having hardness 40-45 HRC was used as the work piece material in which the turning operation held. EN-24 material is consider to be difficult material to cut, therefore authors showed a keen interest to consider this material as work piece. The material was quenched and subsequently tempered for achieving required amount of hardness. The composition and properties are shown in table 1 and 2 respectively.

| Sr. No. | 1   | 2   | 3     | 4     | 5     | 6     | 7     | 8     |
|---------|-----|-----|-------|-------|-------|-------|-------|-------|
| Element | Fe  | Ni  | Cr    | Mn    | C     | Si    | S     | P     |
| Content%| 95.195 - 96.33 | 1.65 - 2 | 0.7 - 0.9 | 0.6 - 0.8 | 0.37 - 0.43 | 0.15 - 0.3 | 0.04 | 0.035 |

| Sr. No. | 1          | 2          | 3          | 4          | 5          | 6          | 7          | 8          |
|---------|-------------|------------|------------|------------|------------|------------|------------|------------|
| Properties | Tensile strength | Yield strength | Elastic modulus | Poisson's ratio | Elongation at break | Hardness   |            |            |
| Metric   | 745MPa      | 470 MPa    | 190-210 GPa | 0.27-0.30   | 22%        | 40-45 HRC  |            |            |
| Imperial |             |            |            |            |            |            |            |            |

2. EXPERIMENTAL CONDITION AND PROCEDURE

2.1 Experimental Setup

The objective of this experiment consists of two major parts. In the first part we had to develop the Minimum Quantity Lubrication system technique which used special air atomizing nozzle for mist formation of the coolant. In the second segment on EN-24 material, the MQL technique was
applied and its surface roughness value was compared with dry and wet conditions. The experiment involved turning operation on cylindrical job of AISI 4340 (EN 24). The experimental setups are shown in figure 1, which include atomizing nozzle (consists of two inlets, one for compressed air and other for lubricant and one outlet having nozzle orifice diameter 0.9 mm.), flow regulator, fixture (for holding the nozzle and proper spraying between the work-piece interface) and other elements. All the turning operations were carried out on lathe machine (Makers: Faridabad control Electrical Pvt. Ltd., Faridabad, India). The coated cutting insert are been preferred over the tool steel material to machined, therefore coated cutting insert have been selected for the study.

Fig.1: Experimental setup

2.2 Turning Condition and Procedure

Experiments have been performed in conventional lathe machine under conventional wet cooling, dry cutting and using MQL techniques. The experiments were conducted under different experimental conditions as shown in table 3 below:

Table 3: Experimental Conditions for Turning

| Work Material | EN-24 (AISI-4340) Tempered (40-45 HRC) Ø70 mm & length 400 mm. |
|---------------|---------------------------------------------------------------|
| Insert Used   | Coated Carbide Tool                                           |
| Insert        | Grade             | CNMG120404        | CNMG120408        | CNMG120412        |
| Designation   | Coating           | PVD AlTiN-Coated  | MT-CVD- TiCN-Al2O3 coated | PVD AlTiN-coated |
| Cutting       | Cutting Speed (In | Depth of cut (in  | Nose Radius (in  | Condition         |
| Parameter     | RPM)              | mm)              | mm)              | Dry, Wet and MQL |
|               | 240,400,575       | 0.2, 0.4, 0.6    | 0.4, 0.8, 1.2    |                 |
| MQL condition | MQL Flow rate     | 200ml/hr         | 5-10 mm          | 1:20             | 7 bar |
|               | Distance from tip |                  | Ratio of Mixture | Air Pressure     |
|               | Ratio of Mixture  |                  |                 |                  |      |
In this study, the wet condition coolant comes in the flood form and causes many changes in different output parameters as compared to dry conditions, but, in the next set of cutting, MQL (Minimum quantity lubrications) condition is used, in which the atomizer nozzle plays an important role. The nozzle is connected with an air compressor at one side and with lubricant on the other side of the inlet. At the exit of the nozzle, the mixture of aerosol (air + lubricant) is achieved and this aerosol sprays into the tool work piece interface (see Fig 2).

![Atomizer](image)

**Fig. 2: Atomizer**

All the experiments are performed under room temperature. To save the resources and time Taguchi’s L9 orthogonal array is adopted instead of Taguchi full factorial design. The design of the experiment is according to Taguchi’s L9 orthogonal array. In this experiment, the output parameter surface roughness value is measured with the help of surface roughness tester Talysurf. The designs of experiment are shown in table 4.

| Trial Run | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|-----------|----|----|----|----|----|----|----|----|----|
| Cutting Speed (in RPM) | 240 | 240 | 240 | 400 | 400 | 575 | 575 | 575 |
| Depth of Cut (in mm) | 0.2 | 0.4 | 0.6 | 0.2 | 0.4 | 0.6 | 0.2 | 0.4 | 0.6 |
| Nose Radius (in mm) | 0.4 | 0.8 | 1.2 | 0.8 | 1.2 | 0.4 | 1.2 | 0.4 | 0.8 |

2.3 **GRA methodology**:

The grey relational analysis is implemented to solve multi-response optimization for both surface roughness value (Ra) and Material Removal rate value in the current paper. The GRA is a method for the optimization which includes several steps. The Grey relational analysis in this study is as follows:
Table 5: Experimental Results and multi-response parametric optimization

| Trial Run No. | Output response | Ra (Dry) (in mm) | Ra (Wet) (in mm) | Ra (MQL) (in mm) | MRR (in mm/3/min) |
|---------------|----------------|-----------------|-----------------|-----------------|------------------|
| 1.            |                | 3.2             | 2.1             | 2.2             | 675.5680         |
| 2.            |                | 4.1             | 3.3             | 3.1             | 1351.1617        |
| 3.            |                | 4.1             | 3.2             | 2.9             | 2026.7810        |
| 4.            |                | 3.1             | 2.2             | 2.1             | 1125.9468        |
| 5.            |                | 3.9             | 2.9             | 1.8             | 2251.9192        |
| 6.            |                | 4.0             | 2.9             | 2.8             | 3377.9172        |
| 7.            |                | 3.3             | 2.5             | 2.7             | 1618.5485        |
| 8.            |                | 3.5             | 2.8             | 2.5             | 3237.1226        |
| 9.            |                | 4.9             | 3.1             | 3.0             | 4855.7224        |

Table 6: Normalization between 0 to 1 and evaluation of Δij for each response

| Trial Run | MRR S/N Ratio | Ra(MQL) S/N ratio | MRR Normalized S/N ratio (Zij) | Ra(MQL) Normalized S/N ratio (Zij) | MRR (Δij) |
|-----------|---------------|-------------------|--------------------------------|-----------------------------------|-----------|
| 1.        | 56.5933       | -6.8484           | 0                               | 0.3691                            | 0.6308    | 1         |
| 2.        | 62.6141       | -9.8272           | 0.3514                          | 1                                 | 0         | 0.6485    |
| 3.        | 66.1361       | -9.2479           | 0.5570                          | 0.8773                            | 0.1226    | 0.4429    |
| 4.        | 61.0303       | -6.4443           | 0.2589                          | 0.2835                            | 0.7164    | 0.7410    |
| 5.        | 67.0510       | -5.1054           | 0.6104                          | 0                                 | 1         | 0.3895    |
| 6.        | 70.5729       | -8.9431           | 0.8160                          | 0.8127                            | 0.1872    | 0.1839    |
| 7.        | 64.1825       | -8.6272           | 0.4429                          | 0.7458                            | 0.2541    | 0.5570    |
| 8.        | 70.2031       | -7.9588           | 0.7944                          | 0.6042                            | 0.3957    | 0.2055    |
| 9.        | 73.7250       | -9.5424           | 1                               | 0.9396                            | 0.0603    | 0         |

Table 7: Grey relation coefficient (with ζ = 0.5), grade and its order

| Trial Run | 1.  | 2.  | 3.  | 4.  | 5.  | 6.  | 7.  | 8.  | 9.  |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Ra(MQL) GCij | 0.4421 | 0.411 | 0.3333 | 0.7275 | 0.663 | 0.5582 | 0.8923 |
| MRR GCij | 0.3333 | 0.4353 | 0.5302 | 0.4028 | 0.562 | 0.731 | 0.473 | 0.7086 | 1 |
| Grey relation grade (Gi) | 0.3877 | 0.7176 | 0.6667 | 0.4069 | 0.4477 | 0.7292 | 0.568 | 0.6334 | 0.9461 |
| Rank | 9 | 3 | 4 | 8 | 7 | 2 | 6 | 5 | 1 |
Table 8: Response table for the mean grey relation grade

| Input parameters | Grey relation grade |
|------------------|---------------------|
|                  | Level 1 | Level 2 | Level 3 |
| A) Cutting Speed | 0.5906  | 0.5279  | 0.7158  |
| B) Depth of Cut  | 0.4542  | 0.5995  | 0.7806  |
| C) Nose Radius   | 0.5834  | 0.6902  | 0.5607  |

By applying the above methodology, the value of $\Delta ij$, grey relational coefficient and the grey relational grade for each quality characteristic computed as shown in table 6 and 7 respectively.

Main effect plot for grey relational grade process parameters over machining of EN-24, the mean Grey relational grade and main effect plot are shown in figure 3. The optimum value of process parameters is chosen corresponding to the higher average grey relational grade. Mean of MRPI are shown in table 8 the optimal condition are A3, B3 and C2. So based on this, optimum parameter are cutting speed 575 RPM, nose radius 0.8 mm and depth of cut 0.6 mm.

3 RESULT AND DISCUSSION

3.1 Graphical Analysis:

Lesser value in case of surface roughness shows better results at different conditions shown in figure 4. The graph of surface roughness value in different parameters w.r.t. MQL condition shown in figure 5.
Minimum quantity lubrication method improves the surface quality with less amount of coolant. Figure 5 shows the result of means value of surface roughness at MQL condition with different cutting parameters.

3.2 Dominant parameter Analysis:
The MQL analysis is being done and shown in the figure 5 and figure 6 below contains all the cutting parameters (Cutting speed, Depth of cut and Nose radius), S/N ratio and means value for analysis. This analysis will define the dominating parameter of the experiment.

| Table 9: Response for Signal to Noise Ratios |
|---------------------------------------------|
| Level | Cutting Speed | Depth of cut | Nose Radius |
|-------|---------------|--------------|-------------|
| 1     | -8.641        | -7.307       | 7.917       |
| 2     | -6.831        | -7.630       | -8.605      |
| 3     | -8.710        | -9.245       | -7.660      |
| Delta | 1.879         | 1.938        | 0.944       |
| Rank  | 2             | 1            | 3           |

| Table 10: Response Table for Means |
|----------------------------------|
| Level | Cutting Speed | Depth of cut | Nose Radius |
|-------|---------------|--------------|-------------|
| 1     | 2.733         | 2.333        | 2.500       |
| 2     | 2.233         | 2.467        | 2.733       |
| 3     | 2.733         | 2.900        | 2.467       |
| Delta | 0.500         | 0.567        | 0.267       |
| Rank  | 2             | 1            | 3           |

As the analysis for the dominant parameters in this experiment is shown by the figure 6, S/N ratio and mean value with other parameters under MQL condition, it can be easily see that the dominant parameter in both the cases is depth of cut, as it gets the first rank. It means that, it affects the surface roughness value in larger amount as compare to other parameters.

Fig. 6: Graph of S/N ratio and Means in MQL

4 CONCLUSION
The current study examine comprehensively on the aspects connected to surface roughness, and there optimization by implementing Grey Relational Taguchi optimization technique. Based on the investigation it is concluded that the design and development of minimum quantity lubrication system show the best result as compare to wet and dry condition because in MQL condition better and improve surface roughness value comes as output.
1) The best trial run condition are achieved at these parametric value which include depth of cut of 0.6 mm, nose radius of 0.8mm and cutting speed of 575 rpm respectively.

2) Depth of cut is considered to be most supreme parameter for output value that is surface roughness. The higher depth of cut led cutting tool to traverse the work piece rapidly increases the chatter which results into the poor surface quality.

3) As the vibration increase with increase in relative motion between tool and work-piece interface which caused thrust force in the tool affect the surface roughness and because depth of cut become most dominant parameters in this experiment with respect to other cutting parameters.

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