Optimization of Machining Parameters of Milling Operation by Application of Semi-synthetic oil based Nano cutting Fluids

Giri Prasad M J1*, A S Abhishek Raaj1, R Rishi Kumar1, Frank Gladson1, Gautham M2

1Department of Mechanical Engineering, Velammal Engineering College, Chennai, India
2Department of Mechanical Engineering, SSN College of Engineering, Chennai, India

Abstract.
The present study is concerned with resolving the problems pertaining to the conventional cutting fluids. Two samples of nano cutting fluids were prepared by dispersing 0.01 vol% of MWCNTs and a mixture of 0.01 vol% of MWCNTs and 0.01 vol% of nano ZnO in the soluble oil. The thermophysical properties such as the kinematic viscosity, density, flash point and the tribological properties of the prepared nano cutting fluid samples were experimentally investigated and were compared with those of plain soluble oil. In addition to this, a milling process was carried by varying the process parameters and by application of different samples of cutting fluids and an attempt was made to determine optimal cutting condition using the Taguchi optimization technique.

Introduction
Machining is often accompanied by a large amount of frictional heat at the tool, work and chip interfaces. This in turn affects the machining parameters such as the cutting force, tool wear and the surface roughness. In order to control these parameters, cutting fluids are employed in metal working processes. Effective cooling and lubrication are the most desirable properties of any cutting fluid. A study by few American institutes stated that 60% of companies spend more than 20% of their total expenses on coolants/lubricants in metal cutting operations [1]. Cutting fluids are categorized into various groups based on their derivatives, the commonly used cutting fluids being mineral oil or petroleum oil, oil-water emulsions, pastes, gels and aerosols. Straight oils are undiluted mineral or petroleum oils. They provide excellent lubrication effect between the tool and the work piece which makes them the fluid of choice for most of the honing operations and several machining processes. But the initial cost of these type of cutting fluids are high, making them unsuitable for most of the operations. Despite their high cost, the straight oil cutting fluids also possess poor heat transfer properties. Soluble oil fluids are stable emulsions of the mineral oil and water with a low oil concentration. These are least expensive and are the most commonly used because of their considerably good lubrication and heat transfer properties. However, since these types of fluids are in a highly diluted form, they tend to lose their properties with time and needs to be continuously replaced. Therefore, there exists a need to improve their properties and sustain them in order to cope up with the severity and complexity of the modern machining operations. Recently many studies have marked a massive improvement in the heat transfer and tribological properties of the base fluids on dispersion of nanoparticles. Nanofluids are stable dispersions of nanoparticles into a base fluid. The commonly used base fluids are water, oil and ethylene glycol. These nanofluids are experimentally found to possess better tribological, thermophysical, optical and electrical properties compared to their parent base fluid. Choi et al., [2] showed an enhancement of 10% in the thermal conductivity and 25% enhancement in the viscosity of the nanofluids, prepared by dispersing 0.5% and 3% of nano Al2O3 in...
distilled water. Hrishikesh et al., [3] produced an enhancement of 7-14% in the thermal conductivity of distilled water by dispersion of 0.011% volume fraction of Au nanoparticles. Out of all the previous studies, distilled water based MWCNTs nanofluids exhibited the highest thermal conductivity with an enhancement of 105% compared to plain distilled water [4]. Various studies have already been carried out by dispersion of nanoparticles into cutting fluids. Nano cutting fluids are the new generation nanofluids, which are obtained by dispersion of nanoparticles into the conventional cutting fluids. Khandekar et al., [5] stated that magnitude of the machining parameters such as wettability, cutting force, surface roughness, tool wear, and chip thickness were reduced by dispersion of 1% volume fraction to the conventional cutting fluid. P Subhash Chandra Bose et al., [6] claimed that a reduction in cutting force and the surface roughness was resulted by the usage of nano cutting fluids prepared by 1% volume and 4% volume of Al\textsubscript{2}O\textsubscript{3} in MQL. Saravana Kumar et al., [7] investigated the performance of the cutting fluid after dispersion of 0.1 wt % of MWCNTs in coconut oil. Various other scientists such as Amrita et al., [8], Padmini et al., [9] have also reported encouraging results of improvement in the machining parameters on application of nano cutting fluids prepared by dispersion of different types of nanoparticles. Most of the previous studies involving dispersion of nanoparticles into the conventional cutting fluids deals with the evaluation of machining parameters that govern the machining process such as the cutting temperature, cutting forces, tool wear and the surface temperature. There are a very few studies that experimentally evaluates the anti-wear and thermophysical properties of the prepared nano cutting fluids [10]. Also in all previous studies, the concentration of the nanoparticles in the nano cutting fluids are high leading to cost addition and increased chances of aggregation of nanoparticles. In the present study, a very small fraction of nanoparticles were used and in order to improve the dispersibility of hydrophobic MWCNTs, an efficient functionalization process was chosen and was carried out to improve the dispersibility of MWCNTs in the solvent. The present study is concerned with the preparation of nano cutting fluids, experimental investigation of their properties, and evaluation of machining parameters by application of the prepared nano cutting fluids and optimization of the evaluated properties by formulation of taguchi technique. In addition to the improvement obtained in the anti-wear properties, thermophysical properties and the machining parameters, the usage of nano cutting fluids allows the execution of machining processes in Minimum quantity lubrication (MQL) resulting in cost reduction [5]. The concept of MQL also reduces the chances of dermatitis and other skin diseases, which arises due to long term exposure of cutting fluids on the labours.

2. Experimentation

2.1. Materials

2.1.1 Nanomaterials. Based on our previous studies, it is apparent that MWCNTs and ZnO nanoparticles do not interfere each other in their functioning and so MWCNT and ZnO nanoparticles were chosen for dispersion in synthetic oil [12]. MWCNTs possess excellent heat transfer properties with a thermal conductivity about 1800W/mK and zinc oxide nanoparticles possess excellent lubrication properties.

| Nanoparticles                                      | Property                                     |
|---------------------------------------------------|----------------------------------------------|
| 1. Multi-Walled Carbon Nanotubes(MWCNTs)          | Appearance- Black Powder                     |
|                                                   | Carbon- 96-99%                               |
|                                                   | OD 20-30nm, ID 8-10nm                        |
|                                                   | Length - 30 µm                               |
| 2. Zinc Oxide Nanoparticles                       | Appearance- White Powder                     |
|                                                   | Particle Size- 100nm                         |
|                                                   | Density- 1.7gm/ml at 25°C                    |
2.1.2 Tool and Work piece

| S.no | Material              | Hardness |
|------|-----------------------|----------|
| 1    | Tool-HSS M 02         | 65 HRC   |
| 2    | Mild steel IS2062     | 72 HRB   |

2.2 Preparation of nano cutting fluid

The soluble oil was prepared by dissolving coolant oil in plain water in the ratio 1:20 followed by stirring using a magnetic stirrer for a duration of 15 minutes. The nanoparticles were purchased from an Indian company called ‘Reinste’. Two samples of nano cutting fluids were prepared by the two step preparation process. The first sample was prepared by dispersing 0.01 vol% of MWCNTs and the second sample was prepared by dispersing 0.01 vol% of MWCNTs and 0.01% vol % of nano ZnO. MWCNTs being hydrophobic undergo aggregation in the dispersion and therefore a covalent functionalization process using acids was carried out to improve their dispersibility. After addition of nanoparticles to the soluble oil, the mixture was stirred using a magnetic stirrer for 1 hour, and was agitated in an ultrasonic agitator for about 2 hours to form a stable nano cutting fluid. Owing to the very small volume fraction of nanoparticles, the cost associated with the preparation process is reduced considerably.

2.3 Evaluation of anti-wear and friction properties

Tribology is defined as the study of wear, friction and lubrication. Anti-wear and friction Properties of the nano cutting fluids were estimated using Pin on Disc Tribometer at a private laboratory Met Mech engineers, India. Pin on Disk Tribometer consists of a stationary pin under applied load in contact with a rotating disc with required lubrication. The pin material chosen was HSS M 02, resembling the tool material. In order to evaluate wear on the pin, the disc must be of a greater hardness than the pin. For this purpose, a 60 Grit Sandpaper was chosen to be the disc material. All the testing sections were rinsed thoroughly with plain cutting fluid. Based on the calculated input parameters, wear and friction of the pin and disc were calculated by the application of different cutting fluids

| Element | Dimension                  |
|---------|----------------------------|
| 1. Pin  | Material – HSS             |
|         | Diameter – 10 mm           |
|         | Length – 32 mm             |
|         | Spherical contact surface  |
| 2. Disc | Material – 600 Grit Sand paper |
|         | Diameter – 150 mm          |
|         | Thickness – 8 mm           |

2.3.1 Load acting on the Pin

Since both lateral and longitudinal forces act on the tool,

\[
\text{Load} = \frac{\text{Shear force}}{\text{Poisson Ratio}}
\]

Shear force of HSS = \(0.8 \times 10^3\) N/mm²

Poisson ratio of HSS = 0.290

Calculated Load = 275.862 N

For convenience a scaling factor = 4 is considered.

Therefore, Applied Load = 70 N
Table 4. Functional specification of Pin on Disc Tribometer.

| Specification        | Value       |
|----------------------|-------------|
| Disc rotation speed  | 1000 rpm    |
| Load on pin          | 70 Newton   |
| Sliding velocity     | 1.13 m/s    |
| Testing time         | 600 seconds |

Table 5. Loss of weight of pin due to wear.

| Cutting fluid sample | Initial Weight of Pin (g) | Final Weight of Pin (g) | Loss of weight of pin (g) |
|----------------------|---------------------------|-------------------------|---------------------------|
| Plain cutting fluid  | 19.183                    | 19.135                  | 0.048                     |
| Cutting fluid + 0.01 vol% MWCNT | 19.130                  | 19.102                  | 0.028                     |
| Cutting fluid + 0.01 vol% MWCNT + 0.01 vol% ZnO | 18.818                  | 18.810                  | 0.008                     |

Fig 1. Variation of wear between the pin and disc by application of different cutting fluids

Fig 2. Variation of friction between pin and disc by application of different cutting fluids
From the results of Fig 1 and Fig 2, it is evidential that dispersion of nanoparticles into a fluid improves its lubrication properties. Nano cutting fluids containing 0.01% vol of MWCNTs and 0.01% vol of nano ZnO produces the least wear and friction between the pin and disk by producing a reduction of about 83% compared to the plain cutting fluid. The wear and friction produced by nano cutting fluid containing 0.01% vol of MWCNTs lies intermediate between the plain cutting fluid and the nano cutting fluid containing MWCNTs and ZnO which accounts for the excellent lubrication properties of nano ZnO. The increased frictional and wear resistance values are due to direct effects such as rolling, filming, sliding and surface enhancement effects such as mending and polishing associated with the usage of nanoparticles [11].

2.4 Properties of Cutting Fluids
Various properties of the cutting fluids and nano cutting fluids were calculated. Viscosity of the fluid was computed using Redwood viscometer and the flash point was measured using the Pensky Marten closed cup apparatus.

Table6. Thermophysical properties of Plain and nano cutting fluids.

| Fluid                    | Nanoparticle Composition       | Density g/cm³ | Viscosity cSt at 40°C | Flash point (°C) |
|--------------------------|--------------------------------|---------------|----------------------|------------------|
| Plain cutting fluid (F1) | -                              | 0.907         | 34                   | 162              |
| Nano cutting fluid (F2)  | 0.01 vol% MWCNTs               | 0.886         | 39                   | 171              |
| Nano cutting fluid (F3)  | 0.01 vol% MWCNTs and 0.01vol% ZnO | 0.843         | 43                   | 178              |

2.5 Machining and optimization
To investigate the performance of the cutting fluids, milling was carried out on a mild steel work piece in a horizontal milling machine. The nano cutting fluid was supplied by gravity feed system under MQL with a flow rate of 10ml/min. Spindle speed, feed rate, depth of cut, type of fluid was chosen as the process parameters to determine the work piece surface temperature and surface roughness. Further in order to optimize the most suitable cutting fluid and machining parameters, taguchi experiments was carried out. L9 Orthogonal array was used as the experimental design for optimization.

Table7. Process parameters for a L9 OA

| Exp | Spindle speed | Feed rate(mm/min) | Depth of Cut (mm) | Fluid used |
|-----|---------------|-------------------|------------------|------------|
| 1   | 250           | 16                | 0.9              | F1         |
| 2   | 250           | 20                | 0.6              | F2         |
| 3   | 250           | 25                | 0.3              | F3         |
| 4   | 510           | 16                | 0.6              | F3         |
| 5   | 510           | 20                | 0.9              | F1         |
| 6   | 510           | 25                | 0.3              | F2         |
| 7   | 830           | 16                | 0.9              | F2         |
| 8   | 830           | 20                | 0.3              | F3         |
| 9   | 830           | 25                | 0.6              | F1         |

3.1 Taguchi Design
Taguchi technique is one of the most powerful tools for determining the optimum operational parameters. By calculating the Signal to Noise ratio (S/N), the parameters that possess significant effect over responses can be effectively calculated [13]. For any machining operation, a minimal
surface roughness and work piece surface temperature is desired; the fluids and the parameters yielding the same are calculated in the study. The S/N ratio is calculated by using the formula:

\[ \text{S/N} = -10 \log \left( \frac{\sum Y^2}{n} \right) \]

where
- \( Y \) = responses for given factor level combination
- \( n \) = Number of responses in factor level combination

4. Results and Discussion

Surface roughness and the cutting temperature were taken as the output response to govern the performance of the prepared cutting fluids. Surface roughness was measured using surface roughness tester and the cutting temperature was measured using thermocouple. All the measured values were tabulated in the Minitab software to perform Taguchi analysis.

| Exp | Spindle speed (Rpm) | Feed rate (mm/min) | Depth of Cut (mm) | Fluid used | Surface roughness (µm) | Cutting Temperature (°C) |
|-----|---------------------|-------------------|------------------|------------|------------------------|--------------------------|
| 1   | 250                | 16               | 0.9              | F1         | 1.864                  | 58                       |
| 2   | 250                | 20               | 0.6              | F2         | 3.676                  | 41                       |
| 3   | 250                | 25               | 0.3              | F3         | 1.687                  | 30                       |
| 4   | 510                | 16               | 0.6              | F3         | 1.137                  | 48                       |
| 5   | 510                | 20               | 0.9              | F1         | 3.31                   | 64                       |
| 6   | 510                | 25               | 0.3              | F2         | 1.747                  | 44                       |
| 7   | 830                | 16               | 0.9              | F2         | 2.587                  | 67                       |
| 8   | 830                | 20               | 0.3              | F3         | 1.769                  | 52                       |
| 9   | 830                | 25               | 0.6              | F1         | 2.611                  | 66                       |

The parameters yielding low surface roughness and cutting temperature were determined using S/N ratio plots and main effect plots for S/N ratio. From the results of the response table (Table 8), the type of cutting fluid is the most significant parameter that affects the surface roughness of the work piece than the other three parameters and the depth of cut is the most significant parameter that affects the cutting temperature than the other three parameters. From the results of the main effect plot of S/N ratios (Fig 3), the cutting parameters for producing least surface finish are the spindle speed of 510 rpm, Feed rate of 16 mm/min, Depth of cut of 0.6 mm by application of nano cutting fluid F3 containing 0.01 vol of MWCNTs and 0.01 vol% of nano ZnO. Also for producing lowest work piece surface temperature, the cutting parameters are spindle speed of 250 rpm, Feed rate of 25 mm/min Depth of cut of 0.3 mm by the application of nano cutting fluid F3. It is therefore evident from the results that both the surface roughness and work piece temperature depend majorly on the properties of the cutting fluid. In addition to this, a remarkable anti-wear properties was observed from the results of Pin on disk apparatus in the case of nano cutting fluid indicating the improvement in tool life.

The parameters yielding low surface roughness and cutting temperature were determined using S/N ratio plots and main effect plots for S/N ratio. From the results of the response table (Table 8), the type of cutting fluid is the most significant parameter that affects the surface roughness of the work piece than the other three parameters and the depth of cut is the most significant parameter that affects the cutting temperature than the other three parameters. From the results of the main effect plot of S/N ratios (Fig 3), the cutting parameters for producing least surface finish are the spindle speed of 510 rpm, Feed rate of 16 mm/min, Depth of cut of 0.6 mm by application of nano cutting fluid F3 containing 0.01 vol of MWCNTs and 0.01 vol% of nano ZnO. Also for producing lowest work piece surface temperature, the cutting parameters are spindle speed of 250 rpm, Feed rate of 25 mm/min Depth of cut of 0.3 mm by the application of nano cutting fluid F3. It is therefore evident from the results that both the surface roughness and work piece temperature depend majorly on the properties of the cutting fluid. In addition to this, a remarkable anti-wear properties was observed from the results of Pin on disk apparatus in the case of nano cutting fluid indicating the improvement in tool life.

| Level | Spindle speed (Rpm) | Feed rate (mm/min) | Depth of Cut (mm) | Cutting fluid |
|-------|---------------------|-------------------|------------------|--------------|
| 1     | -7.086              | -4.927            | -4.781           | -8.047       |
| 2     | -5.453              | -8.886            | -6.920           | -8.136       |
| 3     | -7.142              | -5.908            | -8.020           | -3.537       |
| Delta | 1.730               | 3.960             | 3.240            | 4.599        |
| Rank  | 4                   | 2                 | 3                | 1            |
Table 10. Response Table for S/N ratio (Surface Temperature)

| Level | Spindle speed (Rpm) | Feed rate (mm/min) | Depth of cut (mm) | Cutting fluid |
|-------|---------------------|---------------------|-------------------|---------------|
| 1     | -32.36              | -35.14              | -32.24            | -35.93        |
| 2     | -34.21              | -34.23              | -34.09            | -33.88        |
| 3     | -35.74              | -32.93              | -35.97            | -32.50        |
| Delta | 3.39                | 2.20                | 3.73              | 3.43          |
| Rank  | 3                   | 4                   | 1                 | 2             |

Fig 3. Main effects plot for S/N ratio (Surface roughness)

Fig 4. Main effects plot for S/N ratio (Cutting Temperature)
5. Conclusion
This Experimental study discussed the application of Taguchi tool for determining the optimum machining parameters and their influences on the surface roughness and the cutting temperature. Based on the results, the following conclusions can be made:

1. A remarkable output response was observed by the application of nano cutting fluids as coolants, with the nano cutting fluids prepared by dispersing 0.01% MWCNTs and 0.01% Zinc Oxide nanoparticles exhibiting the most desirable properties.

2. The optimum process parameters for obtaining minimum surface roughness were the spindle speed of 510 rpm, feed rate of 16 mm/min, depth of cut of 0.6 mm by application of nano cutting fluid containing 0.01 vol% of MWCNTs and 0.01 vol% of nano ZnO.

3. The optimum process parameters for obtaining minimum cutting temperature were the spindle speed of 250 rpm, feed rate of 25 mm/min, depth of cut of 0.3 mm by application of nano cutting fluid containing 0.01 vol% of MWCNTs and 0.01 vol% of nano ZnO.

Thus, the study recommends the usage of nano cutting fluids, a dispersion of nanoparticles into the conventional cutting fluids as a substitute to the conventional cutting fluids to improve the tool life and quality of the machined workpiece in order to cope with the severity and complexity of modern machining processes.

6. References
[1] Wisley Falco Sales, Anselmo Eduardo Diniz, Alisson Rocha Machado 2001- Application of Cutting Fluids in Machining Processes- Journal of the Brazilian Society of Mechanical Sciences, Vol 23
[2] Xinwei Wang, Xianfan Xu, Stephen U. S. Choi, 1999 - Thermal Conductivity of Nanoparticle – Fluid Mixture, Journal of Thermophysics and Heat Transfer Vol. 13, No. 4
[3] Hrishikesh E Patel, T Sundararajan, T Pradeep, A Dasgupta, N Dasgupta, Sarit K Das 2005 - A Micro-Convection Model For Thermal Conductivity of Nanofluids, Indian Academy of Sciences Vol. 65, No. 5 physics pp. 863-869
[4] Xiang-Qi Wang and Arun S. Mujumdar 2008, A Review on Nanofluids Part II :Experiments and Applications, Brazilian Journal of Chemical Engineering, Vol. 25, No. 04, pp. 631 – 648.
[5] S. Khandekar, M. Ravi Sankar, V. Agnihotri, and J. Ramkumar 2012 - Nano-Cutting Fluid for Enhancement of Metal Cutting Performance, Materials and Manufacturing Processes, 27: 963–967,
[6] P Subhash Chandra Bose, C S P Rao, Kishore Jawale, Role of Mql and Nanofluids on the Machining of Nicrofer C263 ,(2014), 5th International & 26th All India Manufacturing Technology, Design and Research Conference, IIT Guwahati, Assam, India, pp-1-4
[7] M. Saravana Kumar, K. L. Senthil Kumar, An Investigation Of Multi Walled Carbon Nanotubes Based Nano Cutting Fluids In Turning Of Martensitic Stainless Steel By Using Taguchi And Anova Analysis, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 08-15
[8] M. Amrita, S.A. Shariq, Manoj, Charan gopal, (2014) “Experimental investigation on application of emulsifier oil based nano cutting fluids in metal cutting process” Procedia Engineering 97, 115 – 124
Acknowledgement

We place on record, our sincere thanks to our College CEO, Principal and H.O.D, Mechanical Engineering for granting permission to carry out this work. We thank, Dr. Vidyavathy Balraj, Department of Chemistry, Velammal Engineering College for providing us continuous moral support throughout the project. We also would like to thank Mr. Elumalai and Mr. Umanath for their fruitful technical discussions which were very helpful for completing this work. Heart full Gratitude to Met Mech laboratories for their fruitful support.