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Analysis of Surface Roughness with Different Types of Coolants During Turning of AISI D3 Steel

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In this research work three types of cutting fluids were developed for investigating the better machinability characteristics. After performing the experiments as per Taguchi L9 orthogonal array DoE it was found that surface roughness was lower in Nano cutting fluid with Al_2O_3 nanoparticles. It was found to be lowered by 37-43% and 42-45% as compared to the values obtained with Nano cutting coolant TiO_2 and conventional cutting fluid respectively. The optimized (calculated) and experimental (confirmatory) values of surface roughness were 0.72µm and 0.70µm, found to be in close proximity to each other. SEM analysis was performed. It was found that machined surface with Al_2O_3 Nano cutting coolant was cleaner and smoother as compared to other coolants.
Keywords: Nano cutting coolant, Nanoparticles, Cutting fluid, Optimization.

1. Introduction

Steel is one of the extensively used materials in engineering applications. The properties vary according to the corresponding grades like hardness increments from AISI D1 to D5. In Indian market AISI D3 is used for developing moulding, pressure injection, extrusion dies etc. The material removal process may generate high temperature at the proximity of the cutting tool and workpiece [1-4]. The surface roughness may increment and tool sharpness may get blunt in a short span of time period during machining without the presence of any coolant. Conventional cutting fluid is used for lowering down the machining temperature. The machined component is better in properties like surface finish, morphology etc. The tool wear is lower as compared to dry machining but this use may import certain restrictions due to emergence of toxic fumes may lead to health hazards to the operator like nausea, headache, itching to eyes and skin etc. [5-10]. The steel workpiece may get rusted and the cost to recycling scrape like chips may also get elevated. Emerging high International standards, harder workpiece material and fast production demand alternative coolant techniques. Numerous attempts made by researchers and scientists for lowering down the cutting temperature by using non-conventional cutting fluids. The use of edible and non-edible oils as developed cutting fluids. This reduced the risk factor of the operator's health. The surface roughness improved and tool life incremented. Many researchers use nanoparticles in specified quantities with different types of oils and emulsions. Nanoparticles are classified as water and oil-soluble. Some are readily soluble while some need surfactant for better solubility. The surface roughness declined by 10-25% and tool life incremented by 20-40% [11-17]. Sharma et al. [18] found through a rheological study that viscosity conductivity of Al_2O_3 was better than TiO_2 and conventional cutting fluid. The thermal conductivity was increased by 10.91, 8.42 and 7.4% respectively as compared to room temperature.

Optimization of process parameters seems to be an essential step towards the achievement of sustainability, conservation of energy and resources. The approach is to utilize man, machine and natural resources in coordination with the aim to minimize wastage, losses and errors. Though numerous techniques of optimization are available. Researchers use according to need and requirement but a more popular approach may come out to be Taguchi when the economy may be considered as a major issue. This approach may be used when the raw material is limited and the cost of performing experiments is restricted. This saves more than 50% experiment's performance costs [19-25]. Sharma et al. [26] used Taguchi approach for finding out the better flow rate of aluminia mixed nano cutting fluid. It was found that 150ml/hour was found to be better.

In this research work nanoparticles mixed cutting fluid at the proximity of cutting insert and workpiece at a fixed height. The dropwise fluid supplied in a controlled way resulting in minimal wastage as compared to conventional cutting fluid in flood supply.

2. Experimental Processes

2.1 Preparation of Cutting fluids

Water soluble nanoparticles were selected and procured from the market. A beaker of 500 ml was cleaned with acetone and rinsed weighted on a weighing scale. Zero scale reading was checked and distilled water was filled in the beaker till 500 grams was shown on weighing scale. 5 grams of nanoparticles TiO_2 were weighed on a micro digital weighing machine and mixed in the distilled water. Some rotations were given with a glass rod for manual mixing. The proportion of mixing was 1% (weight by weight). The magnetic stirrer was set for 520 rpm at a room temperature of 21°C for 60 minutes. The beaker was placed aside for half an hour and checked for any particle deposition in the beaker. The five to six times the stirring processes repeated as depicted in Fig. 1(a). The nano cutting fluid filled beakers were placed in a water bath ultra sonicator for further mixing as depicted in Fig. 1(b). It was set for 30 minutes at 30k Hz ultra sonification. The beakers filled with nano cutting fluid were kept outside and rested for 30 minutes. Ultra sonification process was repeated to five to six times. No sedimentation was inspected with the naked eyes. The freshly prepared nano cutting coolant was used for the turning operations as depicted in Fig. 1(c) and Fig.1 (e) respectively. Similarly, Nano cutting fluid was prepared nanoparticles Al_2O_3 (1% weight to weight ratio). A bio-compatible Tween 20 surfactant used to avoid sedimentation by (0.25% weight to weight ratio) and process for magnetic stirrer and ultra sonfication. Later this percentage incremented to 1% weight to weight ratio for proper mixing of nanoparticles. Freshly prepared nano cutting coolant as depicted in Fig. 1(d) was used for experimentation on lathe machine

Fig.1 (e) respectively. The major steps and sequence of nano cutting coolant preparation and machines are illustrated in Fig. 1

Conventional cutting coolant was developed by mixing 1 part of cutting oil and 20 parts of distilled water. The machined workpieces are depicted in Fig. 1 (f).

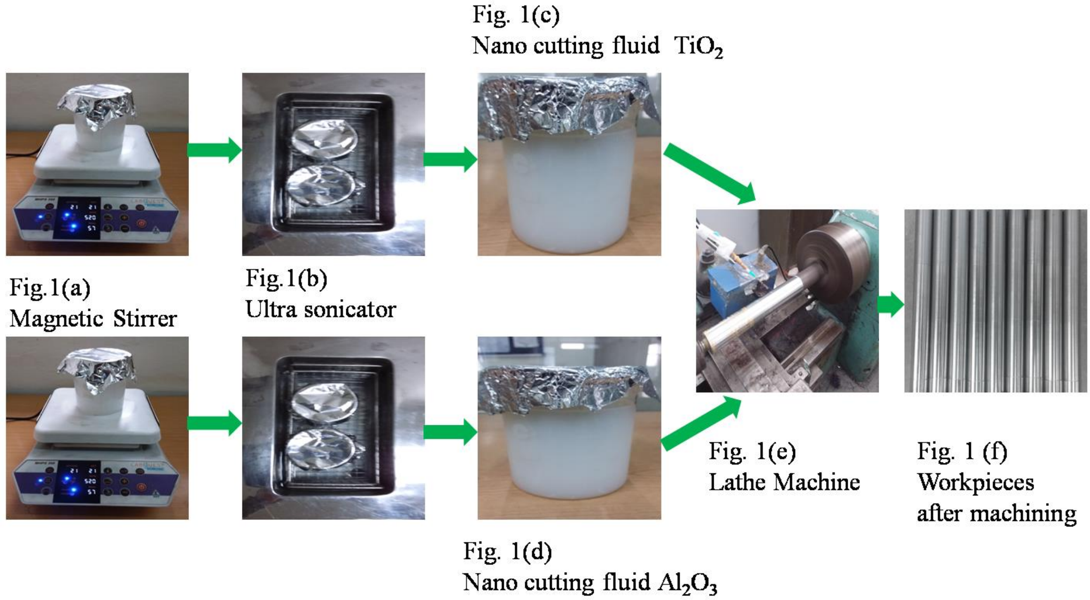


Fig. 1 Illustration of major steps during preparation of nano cutting fluids and machining

2.2 Process of Experiments

The experiments were performed by selecting Taguchi technique for avoiding hit and trial method and economical balance. The three factors and three levels were selected as depicted in Table 1

S No.	Speed (m/min.)	Feed (mm/rev.)	Coolant
1	70	0.09	CON
2	90	0.11	NCTi
3	110	0.13	NCAl

Table 1 Selection of parameters and levels of factors for experimental performance

The surface roughness after machining was measured by contacting type probe surface roughness thrice and the average was recorded for reporting a final value of each experiment. A fresh unused cutting insert was used for the performance of each and every experiment.

3. Results and Discussions

3.1 Surface roughness

The lower surface roughness enhance the life tool and the machined component due to lower residual stress developed. By altering the type of coolants give better results. The performance of experiments accordingly to Taguchi L9 DoE, output values and S/N values of surface are depicted in Table 2

SNo.	Speed (m/min.)	Feed (mm/rev.)	Coolant	Surface roughness	S/N of Surface roughness
1	70	0.09	CON	2.30	-7.23456
2	70	0.11	NCTi	2.20	-6.84845
3	70	0.13	NCAl	0.98	0.17548
4	90	0.09	NCTi	2.15	-6.64877
5	90	0.11	NCAl	1.12	-0.98436
6	90	0.13	CON	2.65	-8.46492
7	110	0.09	NCAl	1.08	-0.66848
8	110	0.11	CON	2.98	-9.48433
9	110	0.13	NCTi	2.59	-8.26600

Table 2 Performance of experiments with output and S/N accordingly L9 DoE Taguchi

The lower the better approach used for deriving the output results as depicted in Eq. (1)

Lower is the better characteristic, $\frac{S}{N} = -10\log\frac{1}{n}(\sum x^2)$ (1)

The S/N value of surface roughness is depicted in Table 2 and means of surface roughness is depicted in Table 3. The lower values are shown in bold are the optimized machining parameters for the performance of better results.

Level	Speed	Feed	Coolant
1	-4.6358	-4.8506	-8.3946
2	-5.3660	-5.7724	-7.2544
3	-6.1396	-5.5185	-0.4925
Delta	1.5038	0.9218	7.9021
Rank	2	3	1

Table 3 S/N values of surface roughness

Level	Speed	Feed	Coolant
1	1.827	1.843	2.643
2	1.973	2.100	2.313
3	2.217	2.073	1.060
Delta	0.390	0.257	1.583
Rank	2	3	1

Table 4 Mean values of surface roughness

The optimized value of surface roughness calculated from the corresponding values of optimized factors from Table 4 according to equation 2 [27]. The value is 0.72µm

$$R_p = \overline{R_p} + \left(\overline{Sd_o} - \overline{R_p}\right) + \left(\overline{Fd_o} - \overline{R_p}\right) + \left(\overline{Ct_o} - \overline{R_p}\right) \qquad (2)$$

During incrementing speed and feed S/N values of surface roughness declined as depicted in Fig.2 (a) and incremented regularly with machining parameter respectively in average values. Nano cutting fluid with Al_2O_3 was better as depicted through data values of Fig. 2(a) and Fig. 2(b)

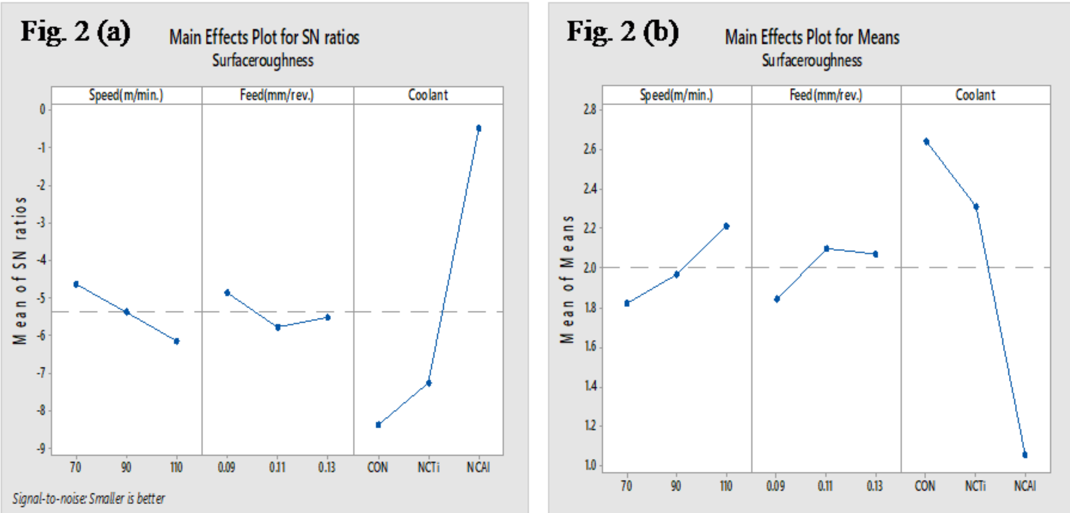


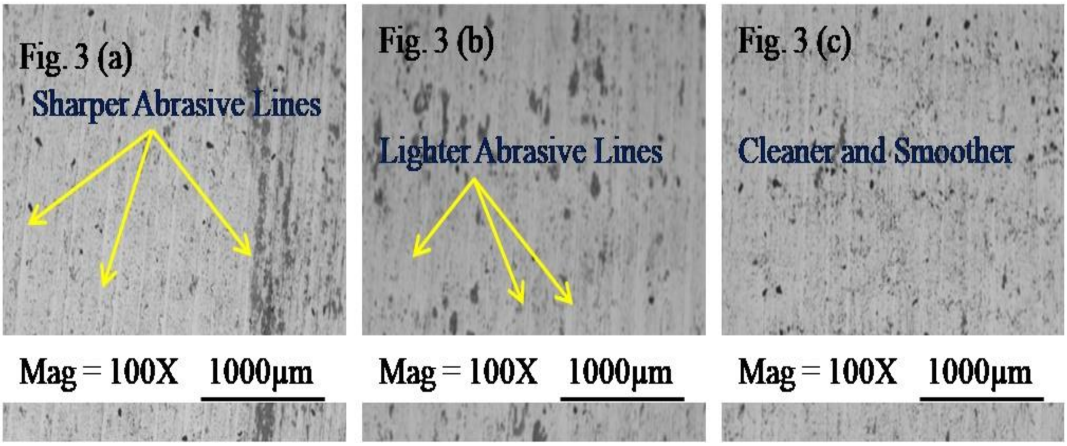
Fig. 2(a) Alternation of S/N values (b) average values of surface roughness

3.2 Analysis of Variance of Means

The analysis performed by ANOVA. It was found that coolant highly influenced the surface roughness with the percentage of contribution of 92.131% subsequently followed by speed by 5.122 %, feed by 2.629 % and error by 0.118 %. Model summary was R - Sq 99.88%, R-Sq (adj) 99.52% and R-Sq (Pred) 97.5%

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% of Contribution
Speed (m/min.)	2	0.23282	0.11641	42.94	0.023	5.122
Feed (mm/rev.)	2	0.11949	0.05974	22.04	0.043	2.629
Coolant	2	4.18669	2.09334	772.14	0.001	92.131
Error	2	0.00542	0.00271			0.118
Total	8	4.54442				

3.3 Surface morphology



The surface morphology analyzed by SEM images of workpiece material AISI D 3 at the speed of 110m/min., feed 0.13 mm/rev., at the supply of conventional cutting fluid, Nano cutting fluid TiO_2 and Nano cutting fluid Al_2O_3 as depicted in Fig. 3 (a), (b) and (c). It was found that some abrasive marks were present on the workpiece machined with conventional cutting fluid. The machined surface was found to be more cleaner, smoother with machining Nano cutting fluid with Al_2O_3 as compared to Nano cutting Fluid TiO_2 and conventional cutting fluid.

4. Conclusions

The turning operation performed on lathe machine with AISI D3 cold worked die steel in accordance with L9 DoE with Taguchi technique with conventional cutting fluid, Nano Cutting coolant TiO_2 and Nano cutting coolant Al_2O_3. The major conclusions drawn as follows:

1 The optimized parameters were found to be speed 50m/min., feed 0.09mm/rev., and Nano cutting coolant Al_2O_3.

2 The highest percentage of contribution of coolant was 92.131% followed by speed 5.122%, feed 2.629% and error 0.118%

3 Surface morphology analyzed by SEM images. The cleaner, smoother and lesser abrasions found on machining with Nano cutting coolant with Al_2O_3.

4 General linear model summary was R - Sq 99.88%, R-Sq (adj) 99.52% and R-Sq (Pred) 97.5%

5 During tuning with Nano cutting coolant Al_2O_3 the surface roughness was found to be lowered by 37-43% and 42-45% as compared to the values obtained with Nano cutting coolant TiO_2 and conventional cutting fluid respectively.

6 The optimized (calculated) and experimental (confirmatory) values of surface roughness were 0.72µm and 0.70µm, found to be in close proximity to each other.

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