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Nanofluids as cutting fluids in minimum quantity lubrication turning operation

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ABSTRACT

In most of the metal industries, the use of cutting fluid has become more problematic in terms of both employee health and environmental pollution. But the use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances and to maintain work piece surface properties without damages. Because of these, some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry machining and machining with minimum quantity of lubrication (MQL). In this paper, experimental investigations for the enhanced cutting fluid properties is studied by inclusion of Al_2O_3 nanoparticles. Surface Roughness, chip formation and tool wear in turning of Mild Steel at different industrial speed-feed-depth of cut combinations by HSS cutting tool are presented and compared with wet machining, MQL machining and MQL with Al_2O_3 nanoparticles. Results indicate that inclusion of Al_2O_3 nanoparticle enables substantial reduction in the cutting tool temperature, tool wear and improve surface finish, which provide better cooling and lubricating in the Machining processes.

INTRODUCTION

The growing demand for higher productivity, product quality and overall economy in manufacturing by machining and grinding, particularly to meet the challenges thrown by liberalisation and global cost competitiveness, insists high material removal rate and high stability and long life of the cutting tools. But high production machining and grinding with high cutting velocity, feed and depth of cut are inherently associated with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the surface integrity of the product. In high speed machining, conventional cutting fluid application fails to penetrate the chip–tool interface and thus cannot remove heat effectively[1]. Addition of extreme pressure additives in the cutting fluids does not ensure penetration of coolant at the chip–tool interface to provide lubrication and cooling[2]. Inappropriately handled cutting fluids may damage soil, water resources causing machine operators skin and breathing problems[1]. Several research workers state that the costs related to cutting fluids with stricter environmental laws are frequently higher than those related to cutting tools. With several limitations of cutting fluids, the search for substitutes is underway. This has given rise to minimum quantity lubrication refers to the use of cutting fluids of only a minute amount-typically of a flow rate of 50-500 ml/h which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition. N.R. Dhar et.al.[3,4] studied the influence of

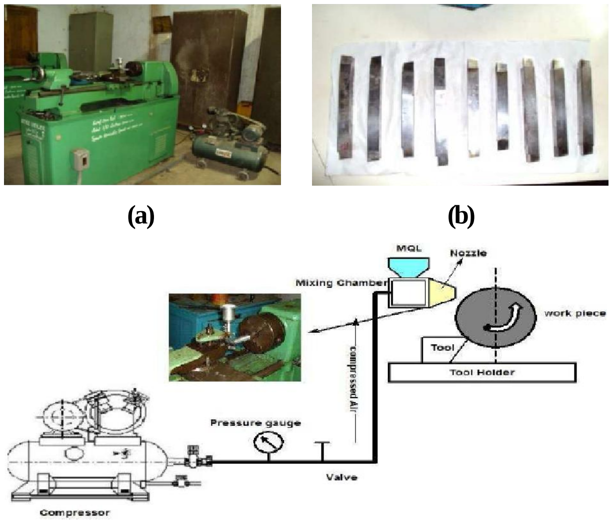

Figure 1 : (a) Photographic view of the experimental set-up (b) HSS cutting tool (c) Schematic view of MQL system

Figure 2 : Mixing of MQL and AL_2O_3 nanoparticles using magnetic stirrer

minimum quantity of lubrication (MQL) on cutting temperature, chip and dimensional accuracy in turning AISI-1040 steel. D.G.Thakur[5] studied optimization of minimum quantity lubrication parameters in High Speed Turning of Super alloy Inconel 718. Further they observed that Also MQL under pulsed jet mode protects the operator's health and reduces the detrimental effects on the environment. Due emerging of Nanotechnology, high thermal conductivity fluids called 'Nanofluids' as emerged. Nanofluids are engineered colloidal suspension of nanoparticle (1-100 nm) in base fluids[6]. The applicability of the fluids as coolants is mainly due to the enhanced thermo physical properties of fluids due to the nanoparticle inclusion[7,8].

The present work experimentally investigates the role of the nanofluid on surface roughness, Tool wear and chip formation in plain turning of mild steel at different speed-feed combinations by HSS cutting tool and compares the effectiveness of MQL nanofluid with that of MQL and conventional cutting fluids.

TABLE 1 : Experimental specifications

Machine tool	GEDEE WEILER, 5hp Lathe
Workpiece:	Mild Steel (size: Ø24mm×100 mm)
Cutting tool	HSS ,Miranda S-400
Working tool geometry	8°, 8°, 6°, 6°, 10°, 15°, 0.8 (mm)
Cutting velocity, V_c	45,60, and 74 m/min
Feed rate, S_c	0.054,0.088 and 0.120 mm/rev
Depth of cut, t	0.2,0.3 and 0.4 mm
MQL supply	Air: 6 bar, Lubricant: 200 ml/h
Environment	Wet (flood cooling) ,Minimum Quantity lubrication (MQL) and MQL with Nano fluids.

TABLE 2 : Process parameter and their levels

Factor	Code	Unit	Level 1	Level 2	Level 3
Cutting Speed	A	m/min	600	0.054	0.2
Feed	B	mm/rev	790	0.088	0.3
Depth of Cut	C	mm	980	0.120	0.4

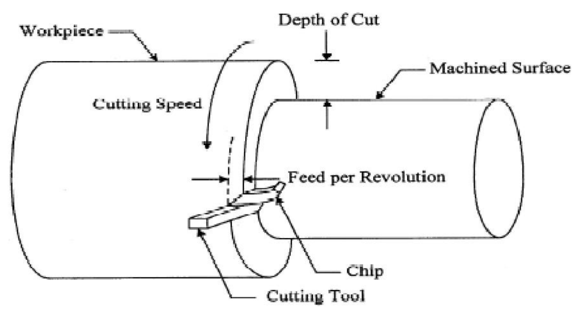

Figure 3 : Parameters in turning operation

EXPERIMENTAL

For the present experimental studies, Mild steel rod of initial diameter 24 mm and length 100 mm was plain turned in a GEDEE WEILER, 5hp Lathe by HSS cutting tool at different speed-feed combinations under, wet condition, minimum quantity lubrication (MQL) conditions and MQL with nanofluid condition to study the role of MQL on the machinability characteristics of that work material mainly in respect of surface roughness, tool wear and chip formation. The experimental conditions are given in TABLE 1. The ranges of the cutting velocity (Vc) and feed rate (So) were selected based on the tool manufacturer's recommendation and

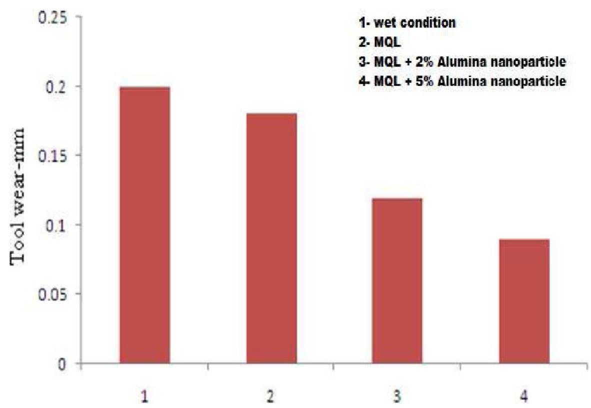

Figure 5 : Machining condition Vs tool wear

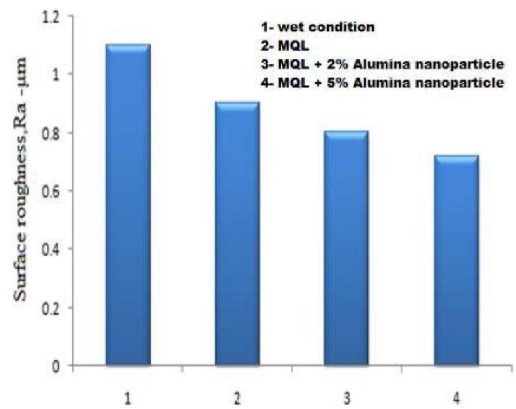

Figure 4 : Machining condition Vs surface roughness

TABLE 3 : Experimental results for wet condition

Expt. No	Cutting speed (m/min)	Feed rate (mm /rev)	Dept of cut (mm)	Surface roughness R_a-µm	Flank wear V_B -mm	S/N ratio for Surface roughness	S/N ratio for tool wear
1	1	1	1	2	0.2	-6.02	13.97
2	1	2	2	2.6	0.24	-8.29	12.39
3	1	3	3	3.8	0.31	-13.44	10.17
4	2	2	3	2.95	0.45	-9.39	6.93
5	2	3	1	4.00	0.4	-12.04	7.95
6	2	1	2	3.8	0.42	-11.59	7.53
7	3	3	2	1.1	0.74	-0.82	2.61
8	3	1	3	2.8	0.79	-8.94	2.04
9	3	2	1	5.12	0.65	-14.18	3.74

TABLE 3a : S/N response table for surface roughness

Symbol	Cutting parameter	Mean S/N ratio (dB)			
		Level 1	Level 2	Level 3	Max-Min
A	Cutting speed	-9.25	-11.00	-7.98	3.02
B	Feed rate	-5.41	-9.75	-13.07	7.66
C	Depth of cut	-10.74	-6.90	-10.39	3.84

The total mean S/N ratio = -9.38 dB

TABLE 3b: S/N response table for tool wear

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	12.17	7.47	2.79	9.38
Feed rate	7.83	6.79	7.14	1.04
Depth of cut	8.55	7.51	6.38	2.17

The total mean S/N ratio = 7.40 dB

industrial practices.

Preparation of nanofluid

In this project we used alumina (Al_2O_3) nanoparticles into vegetable oil as a base fluid to make MQL + Al_2O_3 Nanofluid is given below.

Take the proper amount of Al_2O_3 nanoparticles and directly mix with vegetable oil as a base fluid and make two samples with different proportions of nanoparticles.

I. 2 Vol% of AL_2O_3 nanofluid= 100 ml of vegetable oil+ 2gm of AL_2O_3 nanoparticles

II. 5 Vol% of AL_2O_3 nanofluid= 100 ml of vegetable oil +5 gm of AL_2O_3 nanoparticles

The above composition has to mix continuously about 5 to 6 hours using Magnetic stirrer as shown in figure 2.

Selection of the factors and their levels under taguchi's approach

The cutting experiments were carried out on a GEDEE WEILER, 5hp Lathe by HSS cutting tool for the machining of Mild steel bars. The operating conditions such as speed, feed, and depth of cut and mode of machining (Figure 3) which are generally controllable in any turning situation were selected as factors for study. Therefore the initial cutting parameters were as follows: cutting speed 600 m/min; feed rate 0.054mm/rev; and depth of cut 0.2 mm. The feasible space for the cutting parameters was defined by varying the cutting speed in the range 600-980 m/min, the feed rate in the range 0.054-0.120, and the depth of cut in the range

TABLE 4 : Experimental results for MQL condition

Expt. No.	Cutting speed (m/min)	Feed rate (mm /rev)	Dept of cut (mm)	Surface roughness R_a -µm	Flank wear V_B -mm	S/N ratio for Surface roughness	S/N ratio for tool wear
1	1	1	1	1.95	0.21	-5.80	13.55
2	1	2	2	2.3	0.18	-7.23	14.89
3	1	3	3	4.1	0.27	-12.25	11.37
4	2	2	3	2.65	0.41	-8.46	7.74
5	2	3	1	3.7	0.4	-11.36	7.95
6	2	1	2	3.5	0.39	-10.88	8.17
7	3	3	2	0.9	0.63	0.91	4.01
8	3	1	3	2.5	0.72	-7.95	2.85
9	3	2	1	4.8	0.63	-13.62	4.01

TABLE 4a : S/N response table for surface roughness

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	-8.42	-10.23	-6.88	3.35
Feed rate	-4.45	-8.84	-12.25	7.8
Depth of cut	-10.26	-5.73	-9.55	4.53

The total mean S/N ratio = -8.51 dB

TABLE 4b : S/N response table for tool wear

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	13.27	7.95	3.62	9.65
Feed rate	8.43	8.56	7.85	0.71
Depth of cut	8.5	9.02	7.32	1.7

The total mean S/N ratio = 8.28 dB

TABLE 5 : Experimental results for MQL + 2 % Al_2O_3 condition

Expt. No.	Cutting speed (m/min)	Feed rate (mm /rev)	Dept of cut (mm)	Surface roughness R_a -µm	Flank wear V_B -mm	S/N ratio for surface roughness	S/N ratio for tool wear
1	1	1	1	1.85	0.21	-5.343	13.55
2	1	2	2	2.19	0.19	-6.80	14.42
3	1	3	3	3.9	0.23	-11.82	12.76
4	2	2	3	2.53	0.37	-8.06	8.63
5	2	3	1	3.6	0.34	-11.12	9.37
6	2	1	2	3.3	0.38	-10.37	8.4
7	3	3	2	0.8	0.60	1.93	4.43
8	3	1	3	2.39	0.67	-7.56	3.47
9	3	2	1	4.71	0.54	-13.46	5.35

TABLE 5a : S/N response table for surface roughness

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	-7.98	-9.85	-6.36	3.49
Feed rate	-3.82	-8.49	-11.88	8.06
Depth of cut	-9.97	-5.08	-9.14	4.89

The total mean S/N ratio = -8.06 dB

TABLE 5b : S/N response table for tool wear

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	13.57	8.8	4.41	9.16
Feed rate	8.87	9.08	8.83	0.25
Depth of cut	9.42	9.08	8.28	1.14

The total mean S/N ratio = 8.92 dB

0.2-0.4 mm .Three levels, having equal spacing, within the operating range of the machine were selected for each of the factors as shown in TABLE 1. By selecting three levels the curvature or the non-linearity effects could be studied.

For the given experiment Cutting speed, feed rate and depth of cut were selected as the machining parameters to analyze their effect on surface roughness, chip formation and tool wear as well. A total of 27 experiments based on Taguchi's L9 orthogonal array[9] were carried out with different combinations of the levels of the input parameters. In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. So the S/N ratio represents the amount of variation

TABLE 6: Experimental results for MQL + 5 % Al_2O_3 condition

Expt. No.	Cutting speed (m/min)	Feed rate (mm /rev)	Dept of cut (mm)	Surface roughness R_a -µm	Flank wear V_B -mm	S/N ratio for surface roughness	S/N ratio for tool wear
1	1	1	1	1.14	0.2	-1.13	13.97
2	1	2	2	1.48	0.17	-3.40	15.39
3	1	3	3	3.1	0.21	-9.82	13.55
4	2	2	3	1.8	0.31	-5.10	10.17
5	2	3	1	2.72	0.33	-8.69	9.62
6	2	1	2	2.5	0.29	-7.95	10.75
7	3	3	2	0.9	0.51	0.91	5.84
8	3	1	3	1.5	0.66	-3.52	3.60
9	3	2	1	3.8	0.51	-11.59	5.84

TABLE 6a : S/N response table for surface roughness

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	-4.78	-7.24	-4.73	2.51
Feed rate	-1.77	-5.20	-6.14	4.37
Depth of cut	-7.13	-3.47	-6.14	3.66

The total mean S/N ratio = -5.17 dB

TABLE 6b : S/N response table for tool wear

Cutting parameter	Mean S/N ratio (dB)			
	Level 1	Level 2	Level 3	Max-Min
Cutting speed	14.30	10.18	5.09	9.21
Feed rate	9.99	9.53	10.04	0.51
Depth of cut	9.81	10.66	9.10	1.56

The total mean S/N ratio = 9.85 dB

TABLE 7 : Comparisons at different environmental condition for surface roughness

Exp. No.	Optimal cutting parameter			Environmental condition	Surface roughness R_a-µm
	A Level 3	B Level 1	C Level 2		
1	74	0.0544	0.3	Wet	1.1
2	74	0.0544	0.3	MQL	0.9
3	74	0.0544	0.3	MQL with nanofluid(2vol %)	0.8
4	74	0.0544	0.3	MQL with nanofluid(5vol %)	0.72

TABLE 8 : Comparisons at different environmental condition for tool wear

Exp. No.	Optimal cutting parameter			Environmental condition	Tool wear V_B - mm
	A Level 3	B Level 1	C Level 2		
1	45	0.054	0.2	Wet	0.2
2	45	0.088	0.3	MQL	0.18
3	45	0.088	0.2	MQL with Nanofluid (2vol %)	0.12
4	45	0.120	0.3	MQL with Nanofluid (5vol %)	0.09

present in the quality characteristic[9,10]. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. The S: N ratio η is defined as

$$\eta = -10\log(M.S.D.)$$

Where, M.S.D. is the mean-square deviation for the output characteristic.

Here the desirable objectives are lower values of surface roughness and tool wear. So the lower-the-better type S/N ratio, as given below was applied for transforming the observed data

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

Where, η is the S/N ratio for the lower-the-better case; y_i the measured quality characteristic for the i^{th} repetition; n the number of repetitions in a trial.

Following TABLE 3-6 shows the experimental results for surface roughness, tool life and the corresponding S/N ratio for both under different environment condition using Eq.(1).

All above S/N response table which gives the optimal level of cutting parameter affecting the quality characteristic continuously under different environment condition i.e. wet, MQL and MQL with Al_2O_3 Nanofluids respectively.

RESULTS AND DISCUSSION

From the Taguchi optimization results, it is found that MQL + Al_2O_3 Nanofluids shows reduction in both surface roughness and tool wear than wet and plain MQL condition and it also gives better chip formation than both cutting condition.

Wet machining MQL machining MQL with Nanofluid machining

Figure 6 : Actual forms of chips produced during turning at optimal level of cutting parameter under (a) wet, (b) MQL and (c) MQL with Nanofluid conditions

Surface roughness

From figure 4 indicates that there is a reduction of surface roughness in MQL + 5 % Al_2O_3 nanofluid condition as compare to wet, MQL and MQL +2% Al_2O_3 Nanofluids. This can be due to more intensive temperature and stresses at tool chip interface in conventional cutting condition. It is observed that plain MQL condition gives better surface finish than conventional cutting process depending upon controlling the deterioration of auxiliary cutting edge of abrasion, chipping and built-up edge formation. It is also observed that MQL + 5 % Al_2O_3 nanofluid further decrease in surface roughness, this is due to nanofluids exhibit enhanced thermal properties like higher thermal conductivity and heat transfer coefficients compared to the plain MQL and soluble oil.

Tool wear

Figure 5 indicates reduction of tool wear in MQL + 5 % Al_2O_3 nanofluid condition as compare to wet, MQL and MQL +2% Al_2O_3 Nanofluids .This is due to at high cutting speed, coolant may not have enough time to remove heat accumulated at cutting zone resulting in less reduction of temperature under plain MQL and conventional cutting fluids which leads to more predominant built-up edge formation and increase in tool wear. But in MQL + Al_2O_3 nanofluid machining condition nanofluids help to reduce the temperature resulting decrease of built-up edge formation because of enhanced thermophysical properties of nanofluids.

Chip formation

Figure 6 shows that the mild steel when machined under wet conditions produced spiral type chips and the colour of the chips become blue. This spiral type chip and dark blue colour indicates that there is high temperature between chip-tool interface and reduction of temperature is very less. When machined under plain MQL the form of these ductile chips change appreciably into more or less half turn and their back surface appeared little bit brighter and smoother. This indicates that the amount of reduction of temperature and presence of MQL enabled favourable chip–tool interaction and trace of built-up edge formation. But when machined under MQL + Al_2O_3 nanofluid the form of chip is does not change appreciably than plain MQL condition but the colour of the chips have become much lighter, i.e. metallic from blue due to large reduction in cutting temperature and elimination of built-up edge formation.

CONCLUSIONS

The following conclusions can be drawn based on the experimental results of this experiment:

- MQL is a technique that could reduce many cutting problems coming from high consumptions of lubricant, like high machining costs, environmental and worker health problems.
- Taguchi's robust orthogonal array design method is used to analyze the surface roughness and tool wear problem.
- Surface roughness and Tool wear can be improved simultaneously through MQL + 5% Al_2O_3 nanofluid approach instead of Wet, MQL.

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