Effect of MWCNT Mixed Nanofluid in Turning Operation Using Minimum Quantity Lubrication

Rabesh Kumar Singh[*a], Anuj Kumar Sharma[b], Vimal Mandal[a], Kumar Gaurav[a], Bishwajeet[a], Amit Kumar[a], Amit Rai Dixit[a], Amitava Mandal[a] , Alok Kumar Das[a]

[a]Department of Mechanical Engineering, Indian Institute of Technology (ISM), Dhanbad 826004, INDIA
[b]Department of Mechanical Engineering, Faculty of Engineering and Technology, SRM University Kattankulathur, Kancheepuram, Tamil Nadu, 603203, INDIA

Abstract

In metal cutting operations, machining parameters get restricted up to a certain value due to the generation of large amount of heat at machining zone in dry conditions. Cutting fluid used to cool and lubricate the tool-chip interface and flush away the chips from machining zone. Excessive (flood) use of cutting fluid pollutes the environment and hazardous to operator’s health. Therefore, an attempt was made to reduce the problems of flood machining using minimum quantity lubrication (MQL) without affecting the process performance. In this study, the performance of multi-walled carbon nanotubes (MWCNT) mixed cutting fluid is investigated. The nanofluid samples are prepared by mixing of different concentration of multi-walled carbon nanotubes (MWCNT) in the base fluid. The performance of the nanofluid samples is examined on the turning operation of AISI 304 using minimum quantity lubrication (MQL) technique. Experimental results show that addition of MWCNT in base fluid significantly reduces the components of cutting forces, tool flank wear, surface roughness and cutting temperature. Thus, application of MWCNT nanofluid with MQL improved the overall performance of the machining process.

Keywords: Nanofluid, MWCNT, MQL, Turning, cutting forces, Tool flank wear, Surface roughness, cutting temperature.

1. INTRODUCTION

In Turning is the most commonly used machining operations in the manufacturing industries. During dry machining, a large amount of heat is generated at the tool-workpiece interfaces. Increases in the temperature at cutting zone, increases the cutting forces, surface roughness and lowers the tool life [1]. Therefore, to remove the heat from cutting zone, cutting fluids are used. Growing demand for super alloys and high hardness materials in aviation and defense field requires excellent properties of cutting fluids for machining. Generally, conventional machining is employed with a flood lubrication technique which lubricate the cutting zone and takes away the chip from the surface hence improves the surface finish. However, excessive use of cutting fluid pollute the environment. Various types of coolant and lubricants (chemical based, mineral based and biodegradable oils) are used for machining. These cutting fluids are hazardous in nature, may create various diseases (such as skin and breathing problem) to the operators [2]. Due to the hazardous nature of cutting fluids, disposal and handling become an important concern. In the manufacturing process, cutting fluid covers the 7-17 % of the total cost of production [3].

Therefore, MQL system is being used to overcome the problems of flood machining, which can minimize the excessive utilization of the cutting fluids [4]. MQL (Minimum quantity lubrication) is the method in which cutting fluids (from 15-300 ml/h) combined with highly compressed air (from 4-8 bar) supplied at the machining zone [5]. Utilization of cutting fluid with MQL technique enhanced the machining performance compared to flood and dry machining. Application of MQL technique improves surface finish and takes away the chips from cutting zone [6]. Use of minimum quantity lubrication of near dry machining reduces the different component of cutting forces, tool wear, surface roughness and temperature in comparison to dry machining [7]. Conventional cutting fluid like deionized water, ethylene glycol, vegetable oil and some mineral oil have low thermal conductivity. Therefore, a new type of cutting fluid required, which has higher thermo-physical properties than conventional cutting fluid.

Addition of small fraction of nanometric size non-metallic or metallic particles into the base fluids is called as “Nanofluids”, the term state by Choi [8]. Das [9] studied that suspension of nanoparticles in the conventional fluid increases its thermo-physical properties and wear resistance in compared to conventional fluid. Previous studies show that nanofluids are generally prepared by two different techniques. In the single-step method, nanoparticles are synthesized in a pre-known base fluid. Furthermore, in two-step method nanofluid is prepared by addition of solid nanoparticles in the conventional base fluid followed by ultrasonication. Stability of nanofluid samples is a major problem, due to its higher van-der-Waals attractive forces between the nanoparticles which result in agglomeration [10]. Stability of the nanofluid samples can be enhanced by the adding surfactant to the conventional fluid during ultrasonication. Furthermore, Angayarkanni et al. [11] observed that addition of surfactant in base fluid improves the thermal conductivity and viscosity of the nanofluid. Surfactant occupies interfacial space between the base fluid and nanoparticles which decrease surface tension and enhances wettability of nanoparticles [12]. Temperature and ultrasonication period as well as with the length to diameter ratio (aspect ratio) of the nanoparticles increases the thermal conductivity of nanofluids [13]. Increase in the concentration of nanoparticles in the base fluid increases its thermal conductivity. Furthermore, mixing of nanoparticles into the base fluid forms a protective layer during machining, which reduces the friction, thus result in lower cutting force and better surface finish. Halelfadl et al. [14] and Choi et al. [8] investigated that addition of MWCNT in base fluid for their study, because of its excellent thermal conductivity and higher aspect ratio, close to ∼3000$Wm^{-1}K^{-1}$ and 2000:1 respectively. Various researchers have studied the influence of nanofluid on different machining processes. Roy et al. [15] noticed that use of multi walled carbon

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nanotubes (MWCNT) mixed nanofluid with MQL lowers the cutting temperature as compared to conventional cutting fluid on turning operation. Singh et al. [16] noticed that application of nanofluid improves surface roughness and reduces the cutting forces during turning (cutting) operation. Park et al. [17] again studied the delivery characteristics of the MQL and noticed that delivery parameters of MQL have a significant role in improving the machining performance.

In the present study, the different weight percentage (wt.%) concentration of nanofluid has been prepared by addition of MWCNT in water-based emulsion (95% deionized water + 5% servo cut s-oil). To improve the stability of nanofluids, surfactant Cetyl trimethylammonium bromide (CTAB) is added, and then the samples are ultrasonicated for a longer time. Turing operation of AISI 304 steel is performed on lathe machine with MQL technique. Three trials are conducted at each different weight% (wt.%) concentration at constant machine parameter (cutting speed- 96.2 m/min, depth of cut- 1.0 mm, feed- 0.16). The performance of MWCNT nanofluids with MQL is investigated on turning operation.

2. EXPERIMENTAL SETUP

2.1 Nanofluid preparation

Nanofluid samples are prepared by the addition of different concentrations of MWCNT with water-based emulsion. The water-based emulsion consists of 95% deionized water and 5% servo cut s-oil (Indian oil). The various concentrations of MWCNT (0, 0.2, 0.4, 0.6, 0.8 ,1.0 and 1.2 wt.%) are added in base fluid. The surfactant CTAB (cetyltrimethylammonium bromide) is added to get the homogeneous dispersion of nanoparticles to the base fluids. To get a uniform colloidal suspension of nanofluid, mixtures are ultrasonicated by an ultrasonic vibrator (manufactured by Toshiba, India) which generate pulses of 100 watts at 36±3 kHz frequency for 6 hrs.

2.2 *Turning operation*

Turning operation is performed on AISI 304 stainless steel using a carbide tool inserts on a lathe machine (Model: NH22, 11 kW spindle power manufactured by Hindustan machine tools). Experimental setup includes a dynamometer for force measurement, NI TC01 with k-type thermocouple, tachometer and minimum quantity lubrication (MQL) unit. The Kistler (9047C) 3-compnent piezo-electric type dynamometer is used to measure the cutting forces. The flank wear of the tool inserts is measured by metallurgical microscope (BX51M-Olympus). The small amount of nanofluid with compressed air is supplied by MQL unit at machining zone. For supplying nanofluid, a nozzle is fixed towards the rake surface of the tool insert at 50 mm away. MQL unit supplies the nanofluid at a constant (50 ml/min.) flow rate at 4 bar. The roughness tester (make – Mitutoyo) is used to measure the surface roughness of the test specimen. Table 1 illustrates the machining parameters and detail of measuring instruments.

Table 1. Experimental setup and machining parameter

Machine tool	Lathe (HMT, India).
Workpiece dimensions	Ø 70 mm x 300 mm.
Cutting tool	Uncoated cemented carbide tool inserts.
Feed rate	0.16 mm/rev.
Cutting speed	96.2 m/min.
Depth of cut	1.0mm.
Cutting fluid	Water based emulsion (95% water + 5% Servo Cut S-oil) + MWCNT nanoparticles (0.2, 0.6 and 0.8, 1.0, 1.2 wt.%)
MQL unit	Multi viscosity single nozzle unit (Unist coolube, USA)
Temperature measurement	NI-USB TC01 device (with K-Type thermocouple)
Surf analyzer	Mitutoyo Surftest SJ-210

3. RESULT AND DISCUSSION

In the turning operations, cutting fluids are necessary for diminishing different component of cutting forces. In this regard, an effort has been made to enhance the properties of conventional cutting fluids by the addition of MWCNT. Therefore, different weight percent concentration of MWCNT nanofluid has been used to investigate the effect of MWCNT on various response parameters (main cutting force, thrust force, feed force, tool wear, cutting temperature and surface roughness).

3.1 Effect of component of cutting forces on different concentration of MWCNT nanoparticles.

Components of cutting forces play a significant part in minimizing the energy use in the machining operations. Fig. 1 (a-c) depicts the variation of cutting force, thrust force and feed force with respect to the different concentration of MWCNT nanofluid. The magnitude of all three forces reduces with increase in the percentage fraction of MWCNT. This reduction in the forces achieved due to increase in the thermal conductivity of MWCNT with concentration. However, after 1 wt.% concentration of nanofluid the values of all three forces increase due to cluster formation of nanoparticles at machining zone, which enhances the friction between the workpiece and the tool.

3.2 Effect of tool wear and surface roughness on different concentration of MWCNT nanoparticles.

The accuracy of the product and tooling cost are also the primary concern, and that can affect the machining operation. Fig. 1 (d) and (e) shows the variation of tool wear and surface finish at different percent concentration of MWCNT. The magnitude of tool wear and the value of surface roughness decreases with the increase in the weight percent concentration

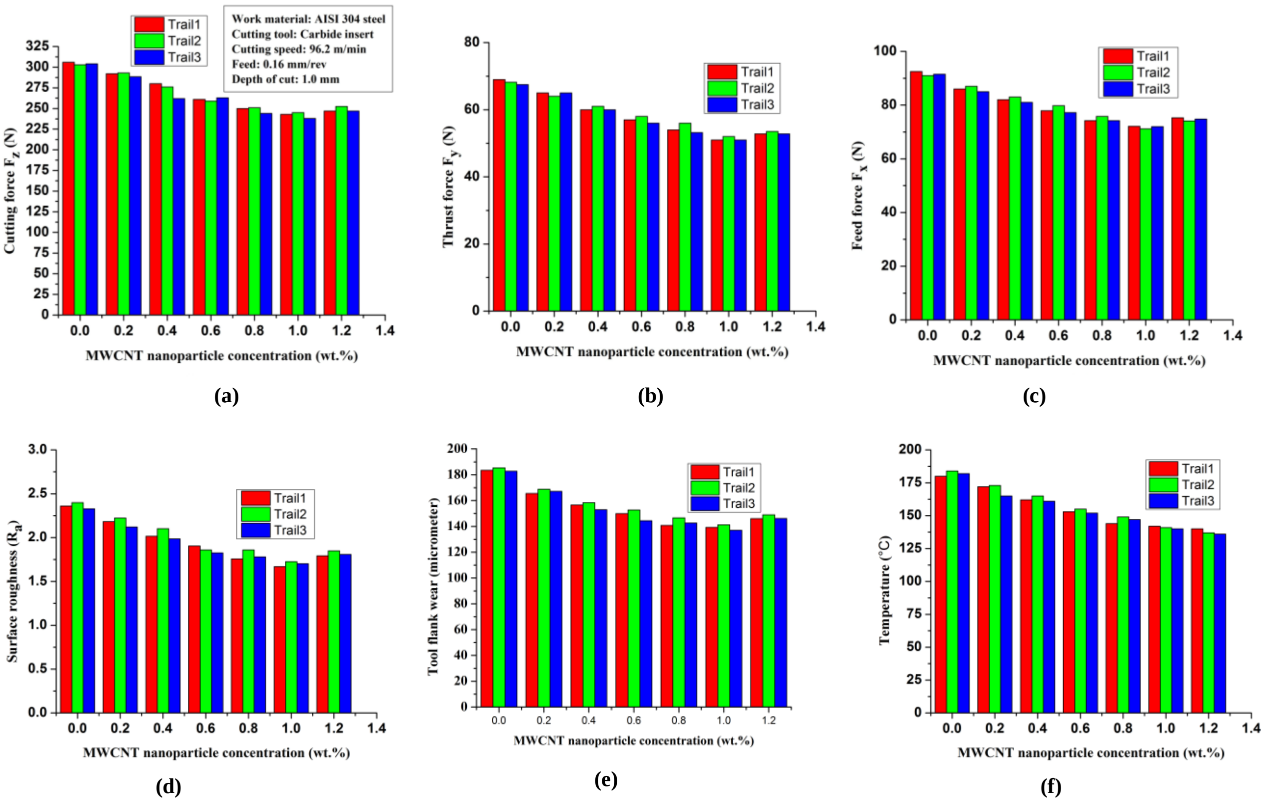

Fig 1 Variation of main cutting force, thrust force, feed force, tool wear, surface roughness and cutting temperature with respect to the different concentration of MWCNT nanofluid.

of MWCNT nanofluid. A thin protective layer formed between the tool-chip interface at machining zone reduces the value of surface roughness and tool wear. Furthermore, surface roughness and tool wear decrease up to 1 wt.% concentration and after that, increases due to the agglomeration of nanoparticles. The viscous nature of nanofluid affected the values of surface roughness and tool wear during machining operations.

3.3 Effect of temperature on different concentration of MWCNT nanoparticles.

During experiments, cutting temperature has been measured at an interval of 1 second. Fig. 1 (f) shows the variation of cutting temperature with different concentration of nanofluids. The outcome of the results indicates that cutting temperature reduces with the application of MWCNT mixed fluid at the machining zone. Cutting temperature decreases with higher weight percent concentration of MWCNT. Reduction of this cutting temperature was noticed due to the higher thermal conductivity of MWCNT, that enhances with an increase in the weight percent concentration of nanoparticles to base fluids. Furthermore, cutting temperature becomes constant after 1 wt. % of MWCNT in the base fluid.

4. CONCLUSIONS

In the present study, turning operation is performed on lathe machine using different concentrations of nanofluids. Various responses like cutting temperature and surface roughness were recorded during experiments. The performance of different MWCNT nanofluid samples was analyzed using MQL. Based on series of analysis following conclusion has drawn:

1) Experimental results showed that when MWCNT added to the base fluid, the cutting forces, thrust force and feed force reduces with higher weight percent concentration of MWCNT to base fluids.

2) Similarly, surface roughness and tool wear also decrease with an increase in weight percent concentration of MWCNT to base fluid.

3) From results, it has been noticed that up to 1.0 wt.% concentration of MWCNT significantly improves the performance of turning operation. However, after 1.0 wt.% it deteriorates the performance.

4) The temperature at the cutting zone decreases with increase in concentration, then remains almost constant after 1 wt.% concentration of MWCNT.

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