International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:10, No:8, 2016

Performance Assessment of Carbon Nano Tube Based Cutting Fluid in Machining Process

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***Abstract*—**In machining, there is always a problem with heat generation and friction produced during the process as they consequently affect tool wear and surface finish. An instant heat transfer mechanism could protect the cutting tool edge and enhance the tool life by cooling the cutting edge of the tool. In the present work, carbon nanotube (CNT) based nano-cutting fluid is proposed for machining a hard-to-cut material. Tool wear and surface roughness are considered for the evaluation of the nano-cutting fluid in turning process. The performance of nanocoolant is assessed against the conventional coolant and dry machining conditions and it is observed that the proposed nanocoolant has produced better performance than the conventional coolant.

***Keywords*—**CNT based nanocoolant, turning, tool wear, surface roughness.

I. Introduction

In machining, because of excessive heat generation and friction produced, quality of the machined surface and the tool wear are affected drastically. Cutting fluids have been used to alleviate this problem. Basically, cutting fluids reduce the tool wear and improve the surface quality in machining, in addition to taking away the chips during machining. However, the use of conventional cutting fluids to meet the above requirements is limited and they carry a lot of drawbacks as well. In view of the above problems, nanofluids as cutting fluids in machining have gained renewed interest. Nanocoolants, with their exceptional cooling properties, have recently emerged as a promising solution.

Nanofluids are the new class of advanced heat transfer fluids engineered by dispersing nanosize particles smaller than 100 nm in diameter in conventional heat transfer fluids [1]. Nanofluids show superior thermal conductivity and heat transfer coefficient due to more surface-to-volume ratio of nanoparticles [2]. Usually, around 2 vol.% of nanoparticles are sufficient to prepare a nanofluid.

Considerably very few investigations have been done into the development of nano-cutting fluids for machining applications. Dinesh et al. [3] applied nanofluid to improve the machining performance of Ti-6Al-4V alloy in grinding. Water based Al_2O_3 nanofluids were considered to investigate the cutting forces and the surface roughness and they observed significant reduction in grinding forces and enhancement in surface quality under the application of nanocoolant. Padmini et al. [4] prepared the micro and the nano-cutting fluids by mixing solid lubricants with coconut and sesame oils separately. Boric acid (H_3BO_3) and molybdenum disulphide (MoS_2) were used as the solid lubricants and it was reported that nanofluids have produced better results when compared with the micro fluids.

Chan et al. [5] improved surface finish in ultra-precision turning using water-miscible nano-cutting fluid. Amrita et al. [6] proposed nanographite based cutting fluid for machining steel under Minimum Quantity Lubrication (MQL) condition. Considerable improvement was achieved with regard to cutting forces, cutting temperature, tool wear, and surface roughness, and it was stated that the improvement was due to effective penetration of droplets of nanofluid in the interface of cutting tool and work piece.

Among the various kinds of nanoparticles, CNT could be the most effective one to disperse. Further, CNT based nanofluids have more viscosity and thermal conductivity [7] which absorbs the heat developed by the machining process that leads to improved surface finish and tool life. Another important characteristic is that nanocarbons are non-toxic [8] and chemically inert. However, a major challenge is faster aggregation and severe sedimentation of CNT in fluids [9]. Therefore, nanofluids after having mixed with CNT are usually subjected to ultrasonication for uniform dispersion.

In view of the above, the present work is intended to investigate the possible applicability of CNT based fluid as a cutting fluid for the hardened EN8 steel which is treated as a difficult-to-cut material. The machining performance of nanocoolant has been assessed against the conventional coolant and dry machining conditions. Flank wear and machined surface roughness are considered the performance measures for the evaluation of the effectiveness of proposed nanocoolant.

II. Experimentation

A. Preparation of Nanocoolant

Multi-walled CNT were added into the commercially available cutting oil (Velvex- Cutvel‘S’). Since the dispersion of CNT is difficult due to faster aggregation and severe sedimentation in fluids, the CNTs were dispersed into the coolant in two stages: magnetic stirring for 1 hour followed by ultrasonication for 3 hours. Figs. 1 and 2 show the stage-wise dispersion of CNTs into the conventional coolant using magnetic stirring and ultrasonication methods respectively. Ultrasonic frequency of 20 kHz was used to generate the

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acoustic waves inside the nanofluid. 1% of TritonX100 surfactant was added as wetting agent ratio for 0.5% CNTs. The surfactant is used as it lowers the surface tension.

Fig. 1 Magnetic stirring

Fig. 2 Ultrasonication

Fig. 3 Thermal conductivity apparatus

Fig. 4 Magnified view of plug and jacket assembly

B. Thermal Conductivity Measurement

Initially, the cutting fluid was prepared as a mixture of water and cutting oil in the ratio of 20:1. The nanocoolant samples containing different weight percentages of CNTs such as 0.1%, 0.2%, 0.3%, 0.4%, 0.5% were prepared individually. The samples were tested for their thermal conductivity. The Hilton thermal conductivity unit was used for the measurement of conductivity of the nanofluids. Fig. 3 displays the thermal conductivity apparatus with a console for the control and display of temperature and heat input. The apparatus basically is a Plug & Jacket Assembly (Fig. 4) containing a cylindrical water jacket and a cylindrical plug. Thermal conductivity was measured through the principle of conduction.

Fig. 5 shows the variation of the thermal conductivity for the additions of CNTs. For the addition of CNTs into the conventional coolant the thermal conductivity is increased up to 0.3% and then decreased as further additions lead to more agglomerations. Therefore, for the investigation of coolant performance, 0.3% CNT dispersed coolant was considered.

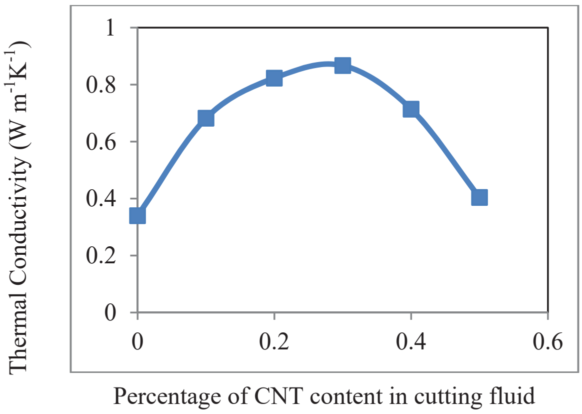

Fig. 5 Variation of thermal conductivity

C. Machining Experiments

The machining experiments were carried out by applying nanocoolant as flood cooling for turning EN8 steel of diameter 50 mm and length 300 mm. The nozzle flow rate was set to 10 ml/min, and the nozzle was placed vertically above the tool work piece interface so that the coolant enters the interfaces properly. Three different cutting environments, viz., i) dry condition, ii) conventional coolant, and iii) nanocoolant conditions were considered, and the cutting tests were performed at the constant set of machining parameters of cutting velocity 40 m/min, feed rate 0.065 mm/rev, and depth of cut 1 mm. The experimentation was performed on all-geared lathe machine with coated cemented carbide tool insert (CNMG120408). The photograph of the experimental setup is shown in Fig. 6.

Fig. 6 Experimental setup

D. Measurement of Reponses

Flank wear and surface roughness of the machined work piece were considered the processes responses to assess performance of the nanocoolant in this investigation. Therefore, while conducting the machining experiments, the machining operation was interrupted at regular intervals, and flank wear was measured. Surface roughness of the work piece in terms of R_a was measured with Mitutoyo make Surftest SJ-301. Surface roughness under each cutting environment was measured at the end of machining. Three samples were machined in each environment to take the average value as the response.

III. Results

The performance of CNT based cutting fluid is compared with that of the conventional coolant and dry machining conditions.

A. Tool Wear

Fig. 7 shows the flank wear of tool at different coolant conditions. It is observed that CNT based coolant has resulted in the minimum tool wear when compared with the other two conditions. This decrease in wear is due to the decrease in cutting temperature caused by CNT based coolant.

As the chosen nano-cutting fluid has better thermal conductivity than the conventional fluid, the usage of the nano-cutting fluid leads to better heat dissipation during machining. Thus, the reduced temperature is prevailed at the interface leading to reduced tool wear.

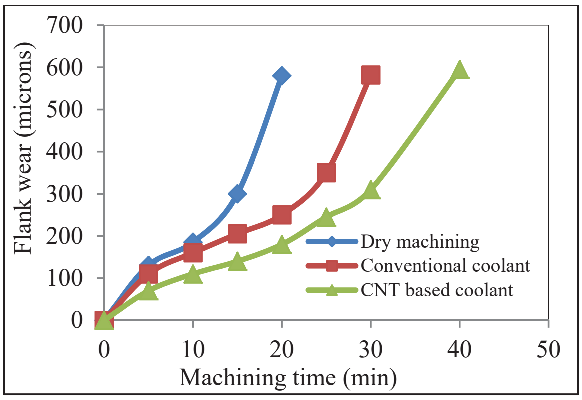

Fig. 7 Flank wear at different lubricating conditions

B. Roughness of Machined Surface

Fig. 8 shows the roughness values obtained under the chosen three different machining conditions. CNT based coolant has yielded better surface finish than dry machining as the presence of cutting fluid always leads to better cooling and lubrication. It is further noted that CNT based cutting fluid has produced better surface roughness than conventional coolant. This would be due to the effective enhancement of cooling and lubricating properties of the proposed nano-cutting fluid.

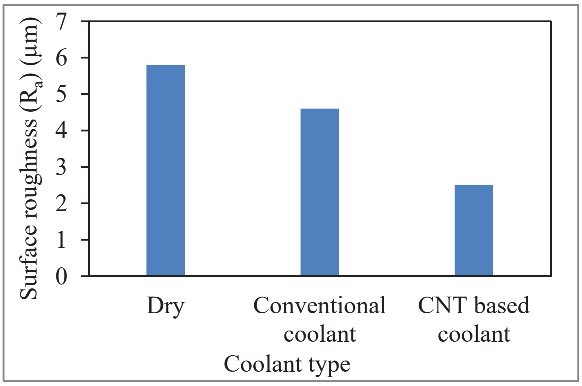

Fig. 8 Surface roughness under different coolant conditions

IV. Conclusions

1. Thermal conductivities of different nano-cutting fluids were found, and it is observed that up to certain percentage of CNTs the thermal conductivity of the fluids increases and then goes down due to the possible agglomerations.
2. The performance of the nano-cutting fluid was investigated in machining EN48 with cemented carbide tool.
3. The machining performance was tested terms of tool wear, and surface finish under different cutting conditions.
4. The obtained results indicate that nano-cutting fluid has produced significant benefits in terms of reduced tool wear and improved surface roughness.
5. Based on the results obtained, it is inferred that the CNT based nanofluids could be used as cutting fluids for better machining performance.

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