EXPERIMENTAL INVESTIGATION OF MINIMUM QUANTITY LUBRICATION EFFECTS IN TURNING PROCESS WITH NANO FLUIDS USING AISI 4320

K. JAGATHEESAN[a,*], K. BABU[b]
[a]*Department of Mechanical Engineering, College of Engineering, Guindy, Chennai, Tamil Nadu, India 600 025*
[b]*Department of Mechanical Engineering, Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam, Tamil Nadu, India 603 110*

In this research work, effect of Minimum Quantity Lubrication (MQL) parameters on the surface roughness of AISI 4320 using nano fluids in turning process. The Multi Walled Carbon Nano Tubes (MWCNT) is used as a nano fluid which tends to increase the tool life and improve the surface quality of the machined product by applying to finish turning of alloys. The turning process outputs such as chip-tool interface temperature, Surface roughness and SEM (to reveal microstructural of the samples) were taken as measurands for evaluating the process efficiency. The performance evaluation of the parameter MQL in turning process of the material was done by relating the outputs at different environment such as different nanoparticle concentration in MQL. The experiment was designed and analyzed with the help of Taguchi design L16 (type – B) method. The lubrication condition plays a deep-seated effect on performance of the product, therefore the timely selection of coolant condition is very vital particularly during cutting of materials with desirable cutting parameters. The surface roughness value of the machined specimen was determined by using surface measurement tester. This study has thus proved that the newly established strategies determined an increase of both tool life and the integrity of machined surface over MQL technique using conventional cutting fluid.

(Received April 5, 2020; Accepted August 24, 2020)

Keywords: MQL, Nanofluid, MWCNT

1. Introduction

Machining, specifically the turning operation has wide applications in manufacturing industries and processes. In modern machining industries are trying to achieve high quality, dimensional accuracy, surface finish, high production rate and cost saving along with reduced environmental impact. But inevitably, problem associated with the turning operation was generation of high heat affected zone, Such high temperature causes dimensional deviation and premature failure of cutting tools. It also impairs the surface integrity of the product by inducing tensile residual stresses and surface and subsurface micro cracks in addition to rapid oxidation and corrosion [1-4]. The lubricants and coolants are the important component of many metal cutting operations. In recent manufacturing trends, to investigate various useful parameters of machining with effective cooling is a rampant technology and the need to sustain severe environmental menaces [5-6].

Minimum Quantity Lubrication (MQL) technique is the technique of atomizing the metal working fluids and providing the minimum quantity to the cutting zone.In MQL method to remove the heat effectively and to increase surface integrity characteristics from micro level to nano level [7-8]. MQL is an alternative for conventional cooling lubrication and environmentally friendly cooling concept [9]. The rapid advancement of nano technology in the last few years has led to the emergence of a new class of coolants called nanofluids. The effects of titanium alloy with MQL mode, the cutting force is less in MQL as compared to dry machining and also the analysis of tool wear and chip morphology and found that feed rate plays important role in producing lower

[*] Corresponding author: jagatheesanphd20@gmail.com

surface roughness [10-11]. In AISI 1040 steel, chips produced in dry and wet lubrication were very long, spiral and blue in color whereas the chips produced in MQL turning were half the length of those produced in dry and wet lubrication and the chips appeared smooth and brighter which denotes a reduction of temperature in the interface [12].

The Nano based MQL with regard to better tooling lifespan and enhanced surface finish over dry cutting and flood machining provides preponderant environmental friendly machining. The important lubrication characteristics of Aluminum oxide assisted nano fluid during machining of D2 hardened steel [13-14]. The aim of the present work is to study the effect of MQL with nano fluids in machining process.

2. Experimental methods

Many researchers had workedto find a surface roughness, tool wear, cutting force by MQL method for the materials of aluminum alloy, high alloyed steels (AISI4340), titanium alloys and etc [1-14]. In this research work, alloy steel AISI 4320 has been selected as a work piece material. This alloy is used in the manufacture of forged gears and pinions and other heavy-duty machinery components. The diameter and length of work piece was 60 mm and 500 mm length respectively. Chemical composition of this material is Fe 96.80%, Ni 1.7%, Cr 0.55%, Mn 0.65%, C 0.22%, Mo 0.3%, Si 0,25%, S 0.04%, P 0.035%. Multi Walled Carbon Nano Tubes (MWCNT) nanoparticles was used as the nano fluidmaterial with the specifications of 10 nm to 30 nm diameter. Ethylene glycolis used for base cutting fluid. The nano fluid were prepared for the experiments by addition of nanoparticles (MWCNT) mixed in the concentration of 1%, 1.5%, 2%.Initially, MWCNT and oil were stirred with the help of a mechanical stirrer for 30 mins. After that, the prepared nano fluid againstirred for 60 mins by using Ultrasonic Vibrator to achieve uniform dispersion.

The MQL tests are carried out using neat base oils (without nanoparticles) and with the same delivery settings as nano fluid tests. The experimentation is adopted Taguchi L16 (Type B) Orthogonal Design method. Number of factors for this method is 5 and levels for each factor is 4. Factors and levels are selected for experimental work shown in Table 1.

Table 1. MQL parameters.

Sl. No.	Factor	Level 1	Level 2	Level 3	Level 4
1	Nano Fluid (Nanoparticles Concentraction %)	0	1	1.5	2
2	Pressure (bar)	4	5	6	7
3	Flow Rate (ml/hr)	50	100	150	200
4	Depth of Cut (mm)	0.5	1	1.5	2
5	Feed (mm/rev)	0.05	0.1	0.15	0.2

The measurement of surface roughness was using Mitutoyo Portable Surface Roughness Tester (Model: Surf test SJ-210 – Standard Drive Unit Type), a user-friendly, compact and complies with many industrial standards.The average of Ra value for the 3 passes has been used for the comparison purpose for deciding the surface finish under each environment. The scratches were observed under SEM to reveal microstructuralof the work samples using ZEISS EVO MA15 SEM and voltages in the range 10–20 kV.

The experimental trials were conducted on the high speed precision MAXTURN++ (MTAB) CNC machine using AISI 4320 as a work piece material having diameter 60 mm, length 250 mm and 277 BHN. at constant speed (1000 rpm). The four values of pressure, four values of flow rate and four level of nanoparticles for cutting fluid, four different DOC and four level of feed are selected to analyze their effect on surface roughness. Taguchi's L16-B orthogonal array were carried out with various levels of the parameters shows in Table 2.

Table 2. L16-B orthogonal array.

Trial No	Nanoparticle (%)	Pressure (bar)	Flow Rate (ml/hr)	DOC (mm)	Feed (mm/rev)
1	0	4	50	0.5	0.05
2	0	5	100	1	0.1
3	0	6	150	1.5	0.15
4	0	7	200	2	0.2
5	1	4	100	1.5	0.2
6	1	5	50	2	0.15
7	1	6	200	0.5	0.1
8	1	7	150	1	0.05
9	1.5	4	150	2	0.1
10	1.5	5	200	1.5	0.05
11	1.5	6	50	1	0.2
12	1.5	7	100	0.5	0.15
13	2	4	200	1	0.15
14	2	5	150	0.5	0.2
15	2	6	100	2	0.05
16	2	7	50	1.5	0.1

3. Results and discussion

3.1. Analysis of chip-tool interface temperature

The chip-tool interface temperature was measured with tool work thermocouple mounted on the machine. The temperature produced while machining has the large influence on tool wear and thus on surface finish produced. In experimental runs, the highest temperature produced was during without nanoparticle machining, as expected, due to absence of any lubricating action in machining area. The variations of chip-tool interface temperature in various machining environments as shown in figure 1. a and b. In comparison of with and without nanoparticles machining, the nanoparticle presents give good result in all trail conditions. From this graph, it was clearly shows the flow rate plays maximum role in the chip-tool interface temperature. It can be also seen from the comparison that the chip-tool interface temperature rapidly increases up to 12 minutes of machining and then following almost a steady trend. The maximum level of nanoparticles gives best result when compare to all other concentration of nanoparticle. This is due to the fact that after few minutes of machining, a thin lubricating film is created between tool and work piece and it has reduced friction and so a maintained the chip-tool interface temperature to steady state.

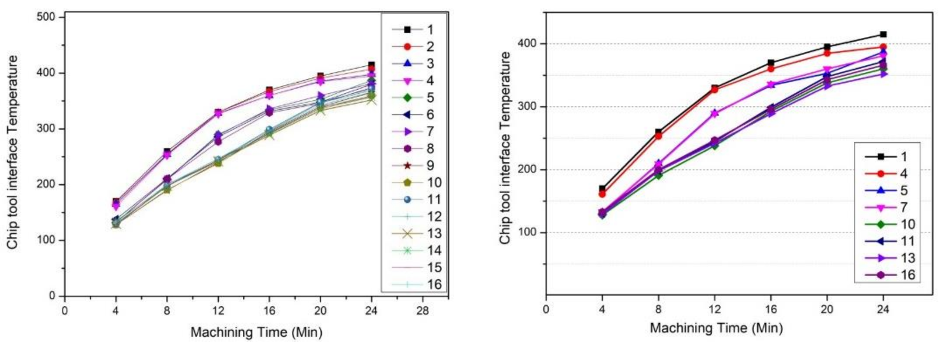


Fig. 1. Variations of chip-tool interface temperature in all trial machining environments.

3.2. Surface roughness

In MQL environment, surface roughness decrease rapidly than machining in without nanoparticles environment. This is due to MQL environment assist to increase rate of heat dissipation and to remove chips from cutting zone with compressed air at the time of machining. The instrument used for measuring surface roughness tester (Surf test SJ-210). From the observation of result analysis, it is also evident that the ethylene glycol fluid mixed with nanoparticle is a most substantial factor affecting surface roughness. The average Ra value for MQL with different nanoparticle mixed was lower than that obtained in dry condition as shown in Fig. 2. This Ra value results in the friction reduction in the cutting zone and hence improved the surface finish in trail no 10.

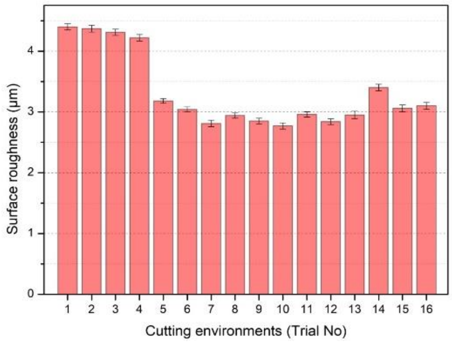
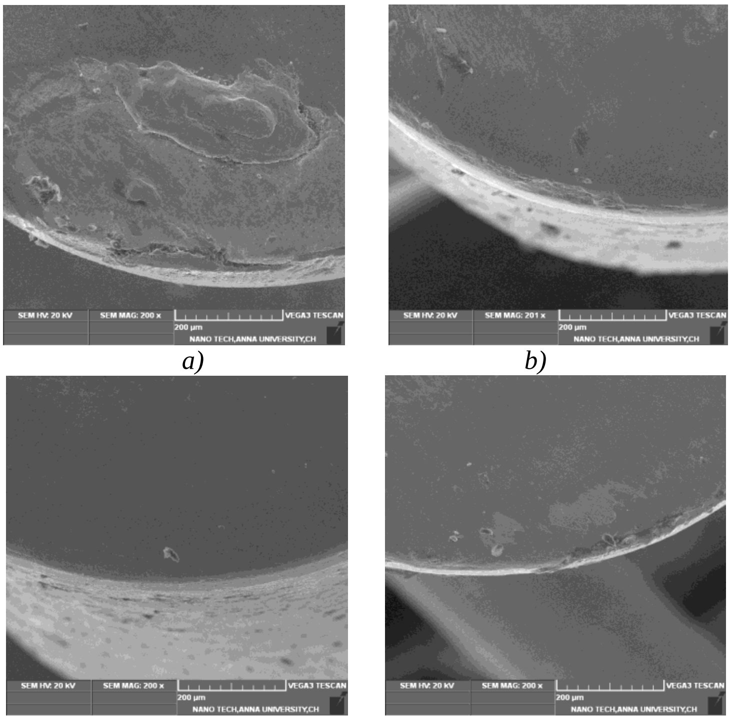


Fig. 2. Surface roughness results.

At lower concentration, the surface finish obtained with the 1% nanoparticle was better than that other concentration emulsion. However, with the increase of concentration much better results in terms of surface finish were obtained compared to without nanopartilces. Other than this, maximum fluid flow rate give better result compare to other parameters like pressure and DOC. Smaller % concentration performed efficiently by creating a thin layer of lubricant film and thus by reducing friction in the machining zone. The experimental results are in established the process performance improved as compared to cutting environmental condition in many ways for surface finish. While comparing the result, it was concluded that the depth of cut and feed rate not majorly effect the surface roughness.

3.3. SEM Micrography

The SEM micrographs from the surface of some selected samples at different lubrication conditions are shown and compared. The samples depicted in Figures (a) without nanoparticles present in trail no 4. (b, c & d) with nanoparticle based in trail no 7, 10 & 13 respectively. As per the work surface texture shown in this figure, the chip removal process has not performed evenly. The results point up that the samples with nanoparticle containing higher quality than the without nanoparticle present. SEM microstructure analysis images show better performance in nanoparticle and no built-up edge formed. Moreover, it can be concluded that the best surface quality is achieved by the MQL processes. If nanoparticles concentration are selected properly in MQL method than the environmental effects of cutting fluids, cutting force, energy to be reduced and improve the quality of the surface of the machined product. Actually, due to high hardness (MWCNT) of nanoparticle tend to scratch the work surface and increase the roughness. In the investigation performance of nano-particles with fluid results micro-fracture and chip removal process has not performed evenly.



a) *b)* *c)* *d)*

Fig. 3. SEM analysis of cutting tool in various machining environments (a) without nanoparticles (b) 1% MWCNT with MQL (c) 1.5% MWCNT with MQL (d) 2% MWCNT with MQL.

4. Conclusions

Based on the results of the present experimental investigation, the following conclusions can be drawn:

MQL had proved some substantial improvements expectedly in respect of chip formation, tool wear and surface finish mainly owed to decrease in the average value of chip–tool interface temperature. In this work surface roughness is the important response parameter under MQL mode with nano fluid. Based on the result, the optimal MQL parameters for surface roughness are maximum fluid flow rate with 5 to 6 bar pressure gives good result compare to other levels.

Surface roughness of material is not significantly affected under varying depth of cut, as feed rate in the experimentation. The improvement in the surface finish was achieved mainly due to the reduction in wear and damage at the tooltip by the application of MQL. The result obtained can be utilized by related industries to develop and establish a sustainable process. The use of lubricant and MQL can be a viable alternative as compared to conventional fluid.

For all measured parameters mixed with 1.5% concentration has performed better by reducing surface roughness and chip tool interface temperature. SEM microstructure analysis images show better performance of nano fluid compare to without nanoparticle in the ethylene glycol lubrication. Moreover, it can be concluded that the best surface quality is achieved by the addition of the MWCNT nanoparticle dispersed in ethylene glycol oil.

References

[1] S. Sharma Vishal, Dogra Manu, N.M. Suri, Journal of Material Processing Technology **49**, 435 (2009).

[2] Dhar Nikhil Ranjan, Sumaiya Islam, MohmmadKamruzzaman, G. U. Journal of Science **20**(2), 23(2007).

[3] P. B. Patole, V. V. Kulkarni, Journal of Materials Today: Proceedings **5**, 12419 (2018).

[4] Binayak Sen, Mozammel Mia, G. M. Krolczyk, Uttam Kumar Mandal, Sankar Prasad Mondal, International Journal of Precision Engineering and Manufacturing-Green Technology,1(2019).
[5] Mayur A.Makhesana, K. M. Patel, Journal of Procedia Manufacturing **33**,43(2019).
[6] S. F. Hosseini, M. Emami, M. H. Sadeghi, Journal of Manufacturing Processes, 244(2018).
[7] B. C. Chetan, Behera S. Ghosh, P. V. Rao, Journal of Tribology International **101**, 234 (2016).
[8] Shrikant U.Gunjal, Nilesh G.Patil, Journal of Procedia Manufacturing **20**, 18(2018).
[9] B. Tasdelen, H. Thordenberg, D. Olofsson, Journal of Materials Processing Technology **203**, 221 (2008).
[10] S. Sartori, A. Ghiottia, S. Bruschia, Journal of Tribology International, 287(2017).
[11] C. Mao, Y. Huang, X. Zhou, H. Gan, J. Zhang, Z. Zhou, Journal of Advanced Manufacturing Technology **71**,1221(2014).
[12] R. Padmini, P. Vamsi Krishna, G. Krishna Mohana Rao, Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 493 (2015).
[13] Puneet Sharma, Balwinder Singh Sidhu, Jagdeep Sharma, Journal of Cleaner Production, 72 (2015).
[14] Y. Shokoohi, E. Shekarian, Journal of Nanoscience and Technology, 59(2016).