NCNE-2020 Special Issue

J. Indian Chem. Soc.,
Vol. 97, July 2020, pp. 1146-1151

Nano cutting fluid is an alternative to hydrocarbon oil based cutting fluid and eliminating solid lubrication in textured cutting inserts

Ch. Divya[a], L. Suvarna Raju*[a] and B. Singaravel[b]

[a]Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research, Vadlamudi-522 213, Andhra Pradesh, India

[b]Department of Mechanical Engineering, Vignan Institute of Technology and Science, Deshmukhi, Hyderabad-508 284, Telangana, India

E-mail: drlsrajuvu@gmail.com

Manuscript received online 10 April 2020, accepted 15 June 2020

In manufacturing industry, machining process and its environmental effect analysis are very important for enhancement of sustainability analysis. In turning process, the heat is generated due to friction, and this heat can be removed by application of cutting fluid. The cutting fluid serves as an agent to cool the cutting tool and provides lubrication between the tool-chip and tool-work piece interface, but it also produces environmental pollution and other operator health issues. To overcome this issue, some research works are focused with different types of textured surface on rake surface of turning cutting tool inserts for sustainability improvement. The present work is focused on application of nano-powder mixed vegetable oil (coconut oil) as coolant for textured cutting tool inserts in turning process. The results of textured inserts with Nano Powder Mixed Cutting Fluid (NPMCF) are compared with solid lubricant embedded textured inserts. The result is concluded that improved machining performance with NPMCF as coolant than solid lubricant textured tool inserts. Textured inserts with NPMCF facilitates infiltration, spreadability and absorption, also provides effective lubrication and cooling function. The results of the investigation revealed that textured inserts with NPMCF is important to obtain the improved machining performance and sustainability.

Keywords: Turning, cutting tool inserts, textures, solid lubricant, vegetable oil, nano Al_2O_3, machining characteristics.

Introduction

Metal cutting is widely used in various fields such as automobile, aerospace and manufacturing industries as a material finishing operation. It is well known that large amount of heat is generated due to friction during metal cutting. Particularly in turning process, heat is generated in both the primary and secondary deformation zone. The conventional method is to reduce the friction and cutting zone temperature by the application of coolant for improving the tribological condition. However, the application of cutting fluid produces environmental pollution, soil contamination, and ground water pollution, harmful to operator health, disposal and further increasing machining cost. Now a day, surface texturing is widely used for cutting tool inserts which is used for sustainability in machining by applying the various grooves on rake surface filled with solid lubricants. Solid lubricants are lubricant materials which are basically solid but soft from frictional heat at the point of contact[1]. Sometimes it produces, chemical reaction between added and parent materials, chemical stability of the particulate addition in relation to the steel matrix and an investigation of changes in their composition and structure. In this work to achieve eco-friendly machining, and to avoid issues related to mineral oil based cutting fluid and solid lubricants, nano powder mixed vegetable oil as coolant used for textured tools are used.

Marques *et al.*[2] used solid lubricant mixed with vegetable oil during Minimum Quantity Lubrication (MQL) turning of Inconel 718. The result observed that molybdenum disulfide (MoS_2) shown better performance in terms of tool life and also observed that lack of oxygen and vapors at the tool-chip interface with graphite as solid lubricant. Zhou *et al.*[3] used micro grooved textured inserts filled with nano-fluid in milling of titanium alloy. The performance of coupling effect of texture with nano-fluid and the results were compared with conventional fluids. The results revealed that mechanism of textured insert, nano-fluid effects and significant improvement in machining performance using textured insert and nano-fluid. Rahman *et al.*[4] investigated the performance analysis of nano-fluid in turning of titanium alloy using vegetable oil as base fluid. The effect of different nano particle (Al_2O_3, MoS_2 and TiO_2) to the vegetable oil (canola and extra virgin oil) at various concentration ratios (0.5%, 2% and 4%) and the properties of NPMCF were investigated.

From the literature, it is observed that to avoid hydrocarbon oil based cutting fluid, textured cutting inserts with solid lubrication are focused. But unfortunately, solid lubrications are reacting with parent materials and there is possibility in chemical reaction. Another problem is with solid lubricant oxidation capability with high cutting zone temperature. In this work, an effort has been made on textured cutting inserts with NPMCF towards sustainability in machining. Very few studies are carried out textured cutting inserts with nano-fluid and not explored much on machinability.

Experimental setup

Nano-fluids are prepared by mixing of nano meter sized particle solid particle to the base fluid. Base fluid may be synthetic oil, vegetable oil, water etc. Al_2O_3 (alumina) is selected nano-particle with less than 100 nm size. Technical specification of selected nano-particle is given in Table 1. Coconut oil is selected as a base fluid. It is a natural product which is biodegradable, non-toxic and renewable category of lubricants. It has higher viscosity, high flash point and good dispersing properties.

Table 1. Technical details of Al_2O_3 nano powder

Nano-particle	Average size	Purity (%)	Melting point (°C)	Boiling point (°C)	Appearance
Alumina-Al_2O_3	57.5 nm	99.90	2072	2977	White

In this work, 0.5% volume concentration is used to mix nano-particles to the base fluid. It is selected based on preliminary studies and literature. In order to ensure homogenous distribution, the nano-fluid is required stirring process. Mechanical, ultrasonic and magnetic stirrers are used to get homogenous distribution. Fig. 1 shows preparation procedure of nanofluid.

Solid lubricant is used in this work MoS_2 with SAE 40 oil in the ratio of 80 to 20. A special device is designed and fabrication to supply constant quantity to the machining zone. Experiments are performed using textured cutting inserts with NPMCF and the results are compared using textured cutting inserts with solid lubrication.

In this investigation, Inconel 718 is considered as work piece materials, which are used for high temperature and corrosion resistance applications. The cutting tool material is used in this work uncoated tungsten carbide (make WEDIA) with grade of CNMA 120408. Turning operations are performed using CNC machine (Pride-Jaguar) with 7.5 kW spindle power.

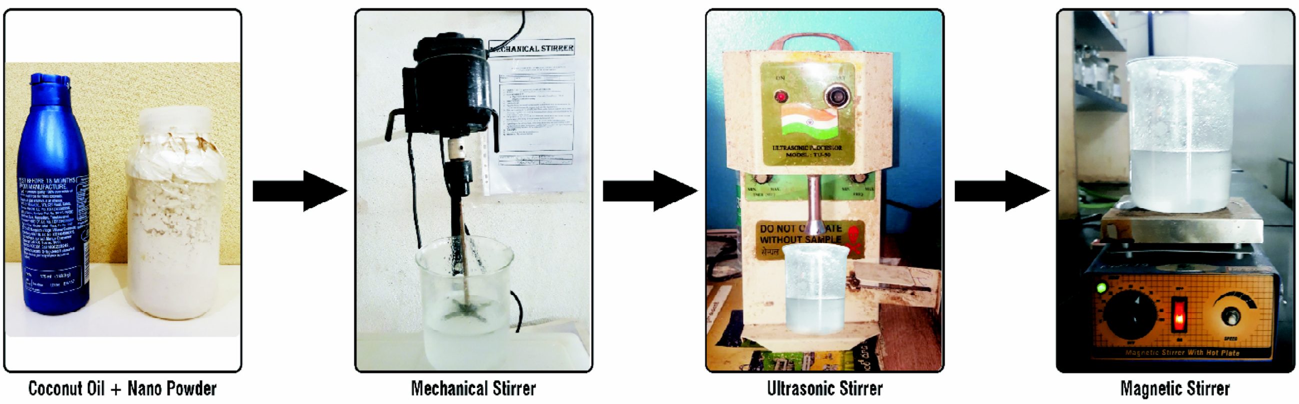
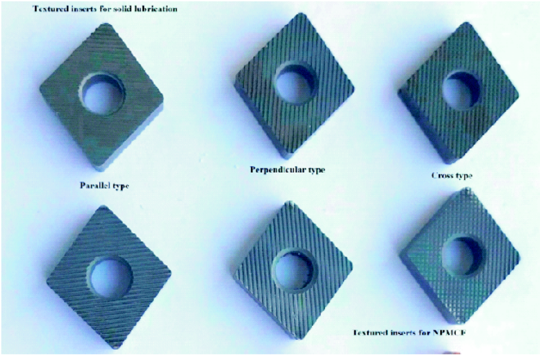
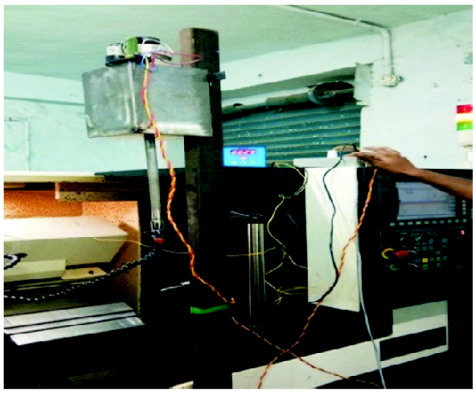


Fig. 1. NPMCF preparation.



(a) Textured inserts



(b) CNC Machine with lubricant supply

Fig. 2. Textured inserts and machine setup.

Textures are produced on the rake surface using WEDM. The texture or groove parameters are groove width (300 μm), groove depth (100 μm) and the distance between two grooves (also known as pitch = 100 μm) are produced using WEDM. Fig. 2a-b shows textured inserts and machine setup.

Taguchi L_9 orthogonal array is used to conduct turning operations. Surface roughness of the machined component is determined by Mitutoyo SJ 210 roughness testing machine (Fig. 3a). Temperature during machining process is measured using FLIR infrared imaging thermometer (Fig. 3b). The experimental results are presented in Table 2.

Results and discussion

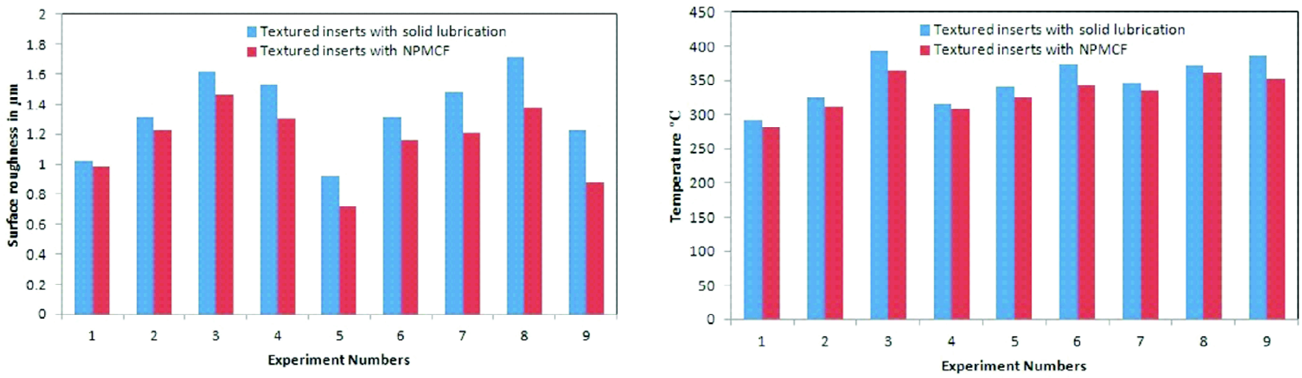
The important functions of cutting fluid are reducing the temperature in the cutting zone and decrease the friction between tool-chip interfaces by providing lubrication. NPMCF provides lubrication functions effectively than solid lubrication.

	
Surface roughness tester	IR thermometer

Fig. 3. Cutting insert surface roughness tester and IR imaging thermometer.

Table 2. Experimental results

Sr. No.	Texture type	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Solid lubrication Surface roughness (μm)	Solid lubrication Temp. (°C)	NPMCF Surface roughness (μm)	NPMCF Temp. (°C)
1.	Parallel	60	0.10	0.50	1.026	292	0.981	281
2.	Parallel	80	0.15	0.75	1.315	325	1.224	312
3.	Parallel	100	0.20	1.00	1.618	394	1.465	365
4.	Perpendicular	60	0.15	1.00	1.528	316	1.308	308
5.	Perpendicular	80	0.20	0.5	0.918	341	0.716	325
6.	Perpendicular	100	0.10	0.75	1.316	373	1.162	342
7.	Cross	60	0.20	0.75	1.482	347	1.208	336
8.	Cross	80	0.10	1.00	1.718	371	1.382	361
9.	Cross	100	0.15	0.5	1.226	387	0.883	352



(a) Variations in surface roughness

(b) Variations in temperature

Fig. 4. Machining performance using solid lubrication and NPMCF.

Fig. 4a shows the surface quality variations with NPMCF and solid lubrication conditions. A good surface quality of a component may improve the working performance by providing good tribological properties. The result of 4% to 27% reduction in surface roughness (Ra) is noticed with NPMCF than solid lubrication condition. Hence, NPMCF shows an improvement in surface quality. This may be improvement due to tribo film layer formed due to NPMCF and creating a mist cloud around the cutting zone[5]. It also generates rolling mechanism which prevents the friction induced wear[6]. This leads to reduction in friction and can be obtained effective lubrication.

Mechanical energy spent for material removal induces high heat in the machining zone. This related study is an important for machinability aspect. NPMCF enhances the thermal conductivity and removes the heat from the cutting zone and heat dissipates from the cutting tool quickly[7]. Fig. 4b shows the variation of temperature during machining process. The maximum temperature noticed is 394°C and 365°C for solid lubrication and NPMCF condition respectively. It will influence on life of the tool and consequence effects as surface quality, tool wear and dimensional accuracy.

NPMCF is developed using nano-solid particles are mixed and blended together. It provides enhanced thermal conductivity, heat transfer coefficient, and viscosity, flash and fire points than the base fluid[8]. It can also used to enhance the tribological properties by providing the action of ball between the contact surfaces[9]. Thermal conductivity and viscosity of the nano cutting fluid are the important parameters to provide on effective lubrication and cooling. Al_2O_3 nano particles are hexagonally closely packed crystalline material and have high hardness, wear and heat resistance[8]. Hence, it shows an excellent lubricity through anti-friction and anti-wear effect property. Table 3 shows the major property and its importance of NPMCF over solid lubrication[5–12].

The surface texture produced on cutting tool is used to reduce tool-chip contact length which is almost equal to a chip breaker. Textured surface can act as small reservoir to store the coolants to be used. Micro groove cutting inserts are retaining lubricant on rake surface; hence increase of lubricity and promotion of anti-adhesion effects at the tool-chip interface[10].

The contact between liquid and solid surface describes wettability. Wettability property of coolants leads to good lubrication. Contact angle of NPMCF has influence on the wettability of the coolants on machined surface. Smaller contact angle indicates, droplets of coolant have capability to spread to larger region[11,12]. This will help to reduce the friction during machining process. Textured surface provides a smaller contact angle, also helping infiltration and spread in to the grooved surfaces[3]. NPMCF has lower surface tension than solid lubricants which facilitate easy spreading, absorbing and leads to effective lubrication[3]. NPMCF provides physical lubrication film by its ductile and flexible prop-

Table 3. Properties of NPMCF

Sr. no.	Properties	Important function	NPMCF	Solid lubricants
1.	Thermal conductivity	Used to reduce temperature in the machining zone followed by thermal degradation	Higher	Lower
2.	Tribological properties	Reduce friction and gives effective lubrication	Higher	Lower
3.	Wettability	Provides good lubrication.	Higher	Lower
4.	Contact angle	Minimum value of contact angle is used to more infiltration and spread large region	Lower	Higher
5.	Surface tension	Easy spread and absorption at low value	Lower	Higher
6.	Recyclable, nontoxic and biodegradation	Environmental friendly	Higher	Lower

erties. The flexibility of NPMCF is squeezed with high extruded force while machining[12,13]. Textured surface inserts with NPMCF has better performance in terms of machining characteristics, thus eliminates dry machining with solid lubrication.

Various direction textures are available namely parallel, perpendicular, cross type and dimple texture[10,14,15]. Among these methods, perpendicular direction textures are used to reduce friction and tool-chip contact length during machining[14]. The lower value of cutting force values are employed during turning process with perpendicular type textured pattern due to the chip flow direction rather than parallel type pattern. In parallel type pattern, adhesion between the tool and chip interfaces was observed[16]. Due to these reason,

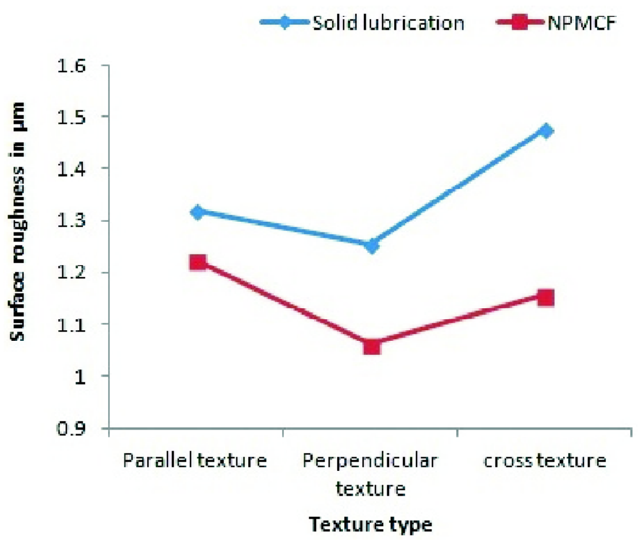


Fig. 5. Effect of textured insets on surface quality.

good surface finish is achieved with perpendicular direction textured cutting inserts. Fig. 5 shows the effect of textured inserts on surface quality.

Conclusions

The textured surface on cutting tool insert promotes excellent lubricity and anti-adhesion effects at the tool-chip interface and acted as chip breaker. Perpendicular type texture provides better performance in terms of machinability.

Textured cutting inserts with solid lubrication drawbacks can be overcome by textured cutting inserts with NPMCF. Textured inserts with NPMCF enhanced cooling and lubrication functions. Hence, reduced surface roughness and temperature. Thus, 4% to 27% reduction in surface roughness and 4% to 7% reduction in cutting temperature using textured inserts with NPMCF compared to textured inserts with solid lubrication.

Textured inserts with NPMCF facilitates contact angle, wettability, infiltration to the grooves and spreadability of NPMCF while machining.

Vegetable oil is a natural product and biodegradability. Al_2O_3 is easily available good tribological properties and low cost nano powder. The size, volume concentration and types of the nano-particle and its studies are further important.

Acknowledgements

This work was supported by the DST-SERB, India [ECR/2017/0001097].

References

1. S. Debnath, M. M. Reddy and Q. S. Yi, *J. Clean Prod.*, 2014, **83**, 33.

2. A. Marques M. P. Suarez, W. F. Sales and A. R. Machado, *J. Mater. Process Tech.,* 2019, **266**, 530.
3. Z. Zou, L. He, H. Jiang, G. Zhan and J. Wu, *Wear.,* 2019, **420**, 163.
4. S. S. Rahman, M. Z. I. Ashraf, A. N. Amin, M. S. Bashar, M. F. K. Ashik and M. Kamruzzaman*, J. Clean Prod.*, 2019, **206**,180.
5. J. S. Nam, P. H. Lee and S. W. Lee*, Int. J. Mach. Tool Manu.*, 2011, **51**, 649.
6. N. Talib and E. A. Rahim, *Tribol Int.,* 2018, **118**, 89.
7. S. Þirin and T. Kývak, *Tribol Int.,* 2019, **137**, 180.
8. Y. Wang C. Li, Y. Zhang, M. Yang, B. Li, L. Dong L and J. Wang, *IJPEM-GT*, 2018, **5**, 327.
9. C. V. Yýldýrým, M. Sarýkaya, T. Kývak and S. Şirin, *Tribol Int.,* 2019, **134**, 443.
10. V. Sharma and P. M. Pandey. *Mater, Manuf, Process.,* 2016, **31**, 1904.
11. C. Y. Chan, W. B. Lee and H. Wang, *Int. J. Mach. Tool Manu.,* 2013, **73**, 62.
12. Y. Zhang, C. Li, D. Jia, D. Zhang and X. Zhang, *Int. J. Mach. Tool Manu.,* 2015, **99**, 19.
13. M. Yang, C. Li, Y. Zhang, D. Jia, X. Zhang, Y. Hou, R. Li and J. Wang, *Int. J. Mach. Tool Manu.,* 2017, **122**, 55.
14. B. Yýlmaz, S. Karabulut and A. Güllü, *J. Manuf. Process.,* 2018, **32**, 553.
15. D. Arulkirubakaran, V. Senthilkumar and V. Kumawat, *Int. J. Ref. Hard. Mater.,* 2016, **54**, 165.
16. N. Kawasegi, H. Sugimori, H. Morimoto, N. Morita and I. Hori, *Precis. Eng.,* 2009, **33**, 248.