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Experimental Investigation of Nanoalumina-sunflower Oil Fluid as Cutting Fluid in Machining Process

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ABSTRACT

The current goal in manufacturing industries is to achieve clean and eco-friendly machining. Researchers are exploring cutting tool inserts with textured rake faces combined with solid lubricants to promote a cleaner machining process. However, solid lubricants present challenges, including difficulties in supply methodology and limited durability at high temperatures. Nanofluids are gaining attention as a sustainable alternative to conventional cutting fluids in manufacturing industries, with increased focus on their potential benefits. To address this issue, two approaches have been explored. The first involves coating textured cutting inserts with a titanium nitride (TiN) ceramic layer, while the second approach uses a nano cutting fluid, which is a mixture of vegetable oil and nano powder. A micro hole pattern texture is introduced to the rake face using Electric Discharge Drilling (EDD) to enhance the dimensional accuracy of the micro holes. Aluminium Metal Matrix Composite (Al-MMC) with MWCNT is used as workpiece material. The machining performance is analyzed based on input parameters such as machining speed, feed rate, and depth of cut, with surface roughness and power consumption as the output parameters. The results conclude that machining performance is improved with nano cutting fluid compared to ceramic-coated and solid lubricant-filled textured tool inserts, showing a 7% to 10% reduction in surface roughness and a 9% to 20% decrease in power consumption when using textured inserts. The challenges of solid lubrication are overcome through the use of a nano cutting fluid environment and TiN ceramic-coated tools.

Keywords: Textured cutting inserts; Solid lubrication; Ceramic coating; Nano cutting fluid.

1. INTRODUCTION

In the metal cutting process, heat is generated due to plastic deformation, which can be reduced using cutting fluids. While industries commonly use hydrocarbon oil-based cutting fluids, they pose environmental concerns. These fluids typically lead to issues such as contamination, groundwater pollution, health risks for operators, and challenges related to disposal (Laghari *et al.* 2023; Saini and Singh, 2022; Saikrupa *et al.* 2022; Debnath *et al.* 2014). To address these issues, various approaches are being explored to transition towards green manufacturing. Textured cutting inserts combined with vegetable oil-based nano cutting fluid (mixed with nano powder) offer significant advantages by promoting environmentally friendly dry machining. This approach eliminates the need for conventional cutting fluids and solid lubricants, fostering sustainability in the machining process.

One alternative cutting method preferred by researchers is texturing combined with solid lubrication. Micro holes or grooves are created on the rake face of cutting inserts and filled with solid lubricants to enhance sustainability in machining (Sharma *et al.* 2015). The textured area with solid lubrication has been found to provide a lubrication effect at the tool-chip interface. The superior lubrication properties of solid lubricants create a thin lubrication film when frictional heat is generated (Dinesh *et al.* 2015; Krishna and Rao, 2008). There are several challenges with solid lubrication, including its delivery to the machining zone, potential chemical reactions with the workpiece materials, oxidation at temperatures above 500°C, and concerns about its durability (Lawal *et al.* 2012) . Therefore, ceramic-coated textured inserts are used combined with a nano cutting fluid under dry conditions. Tungsten carbide tool is the first preference by manufacturer due to low cost and easy availability (Zhang and Zhu, 1993). Various ceramic coated (titanium nitride, alumina and titanium carbide) tungsten carbide tools are available in the market. Titanium nitride (TiN) based ceramic coated cutting inserts are preferable due to their mechanical properties, low coefficient of friction between tool-chip interface, wear resistance and good machinability (Lawal *et al.* 2014). Nano cutting fluid is preferred to promote pollution free machining. Sustainability in machining is enhanced by introducing micro holes or grooves on the rake face of the cutting inserts and embedding them with solid lubricants (Divya *et al.* 2022). Textured area with solid lubrication provides lubrication effect on tool-chip interface. Micro pattern on cutting surface reduces friction between tool and workface, acts as chip breaker, reduces tool chip contact and chip evacuation, helps in recutting of chips and acts as a retainer for solid lubricant (Singaravel and Selvaraj, 2016). Some issues exist with solid lubrication such as, durability, supply to the machining zone, chemical reaction with parent materials, oxidation at a temperature above 500℃ (Lian *et al.* 2013; Lawal *et al.* 2012).

Fig. 1: Electromagnetic stir casting setup

Another cutting condition namely cryogenically treated cutting tool inserts are preferred to promote dry machining. Treatment in cryogenic condition is a type of heat treatment process which is used to enhance the properties of cutting tool. Solid lubricants (e.g., molybdenum disulfide) increase the density, secondary carbide formation and homogeneous distribution which leads to increase the hardness and wear resistance. chemical reaction of solid lubrication. Amato and Martinengo (1973) investigated about solid lubricant coating and its performance improvement in high temperature applications. In their work, CaF_2 was selected as solid lubricant and its wear and frictional coefficient were determined. Surface film was most important in reduction of coefficient of friction. Tannous *et al*. (2011) investigated the tribochemistry of inorganic fullerene-like MoS_2 nanoparticles as anti-wear additives, revealing that a tribofilm of 2H-MoS_2 forms only on steel surfaces, incorporating into an iron oxide layer. Zhang *et al.* (2017) used soft and hard coating on textured cutting inserts in turning process. Physical vapor deposition process was used to carry out soft coating (WS_2) and hard coating (TiAlN). Textures were introduced on rake face by LASER source and a significant improvement in machining performance was observed with hard coating. Mishra *et al*. (2018) characterized the machining performance of AlTiN and AlCrN coated laser textured cutting inserts. They studied the coating morphology, elemental analysis and machining performance on titanium alloy with dry conditions using coated inserts. The results showed enhanced performance with coated textured inserts.

Zhou *et al*. (2019) investigated the use of micro-grooved textured inserts filled with nanofluid in the milling of titanium alloy. They found that the combination of textured inserts and nanofluid significantly improved machining performance by enhancing the effects of both the insert texture and the nanofluid. Rahman *et al.* (2019) conducted a performance analysis of nanofluid in the turning of titanium alloy using vegetable oil as the base fluid. They explored the effects of various nanoparticles mixed with vegetable oil at different concentration ratios.

Micro-texturing techniques using LASER and EDD have shown both advantages and limitations in certain aspects. Therefore, the present work aims to combine the benefits of textured cutting inserts, ceramic coatings, and nano cutting fluid environments. The performance of surface roughness is compared between ceramic-coated inserts and nano cutting fluid environments in the turning of Al-MMC.

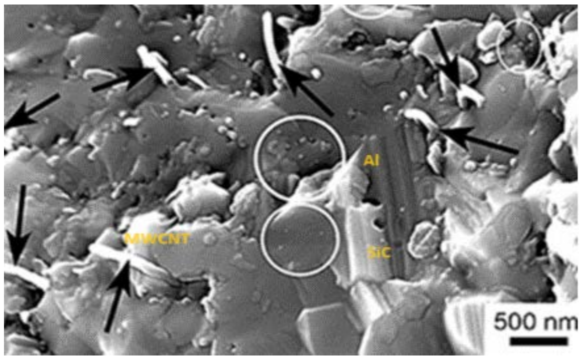

Fig. 2: SEM Image of Al-SiC-MWCNT

2. METHODOLOGY

Electromagnetic stir casting route was used to prepare Al-MMC (Aluminum based Metal Matrix Composites). Fig.1 shows the electromagnetic stir casting setup.

In stir casting, liquid metal flow can be controlled using electromagnetic field. Due to the presence of magnetic field, Lorentz force (force per unit volume) influences the electromagnetic force and better stirring action is achieved and will be useful to obtain defect free composite. Two main parts of Al-MMC are matrix and reinforcement. Al 6061 alloy was used as the matrix and silicon carbide (SiC) with MWCNT nano particles as reinforcement. SEM images can be used to analyze tool wear, surface roughness, and microstructural changes in the machined material. The SEM image of Al-SiC-MWCNT with SiC (Fig. 2) shows a synergic effect, resulting in improved strength and dispersion. The SEM images and optical micrograph images of the fabricated metal matrix composites (MMCs) of various compositions show a homogenous distribution of reinforcement and a strong binding between the MWCNT and AA6061 matrix in the composites. This demonstrates the efficiency of stir casting for producing AA6061-MWCNT MMCs. In comparison to the original metal, the microhardness and impact strength have increased in the MMCs.

Table 1. Al SiC MWCNT material composition

S. No.	Material	Weight %
1	Magnesium	1%
2	Silicon	12%
3	MWCNT	1%
4	Aluminium	Remaining

Energy Dispersive X-ray Spectroscopy (EDX) is an analytical technique used in conjunction with SEM to determine the elemental composition of a sample. Fig. 3 shows EDX image of Al-SiC-MWCNT. EDX identifies and quantifies the elements present in the sample by analyzing the characteristic X-rays emitted when the sample is bombarded with the electron beam.

Table 2. Micro hole textured inserts design parameters

Design parameters of micro hole	Diameter of micro hole	Depth of micro hole	Distance between micro hole
	300 μm	400 μm	350 μm

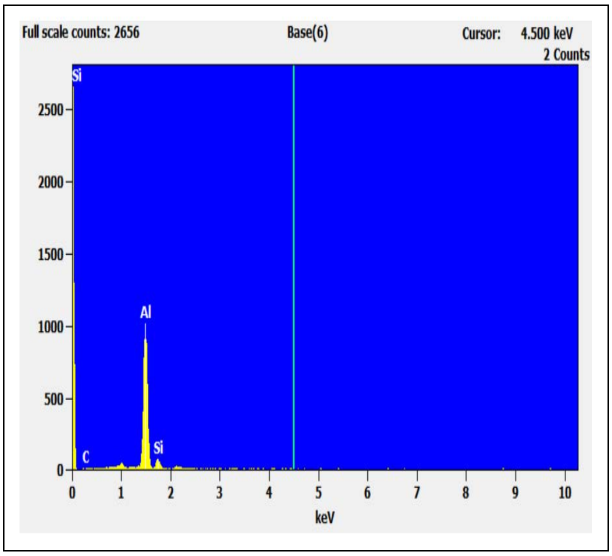

Fig. 3: EDX image of Al-SiC-MWCNT

Plain geometry with uncoated carbide inserts was selected as cutting tool inserts (make WEDIA-CNMA 120408). Liquid-based lubricants are hazardous to the environment and contaminate the soil. Thus, this study considers alternate Electrical discharge drilling method is used for producing texture on cutting tool inserts. Generally, researchers use LASER source for introducing texture on rake face. But there are a few limitations such as dimensional accuracy and heat zone. Fig. 4 shows EDD and LASER source used for texture produced on cutting inserts. Fig. 5 shows the SEM image of hole produced by EDD and LASER source. Fig. 6 shows cutting inserts with micro-hole. Diameter of the hole, depth of the hole and pitch between the holes have been selected as design parameters based on literature and trial experiments. Table 2 presents the design parameter levels. Experiments were performed with the help of Taguchi L_9 orthogonal array. Turning process is carried out using CNC turning machine (make of Pride-Jaguar). Table 3 shows the process parameters used to perform experiments. Texture on cutting tool inserts is used for filling solid lubricant and providing appropriate cooling and lubrication. The important task in the solid lubrication is to supply appropriate quantity to the cutting zone. It is directly filled in the groove manually. In this investigation, a supply device was used to achieve solid lubrication. Fig. 7 illustrates the nano-fluid preparation process. Fig. 8 shows the CNC setup with solid lubrication supply system. Tungsten disulphide (WS_2) was selected as solid lubricant. Textured insert was coated with TiN ceramic element for promotion of dry machining as well as sustainability of machining. TiN has excellent lubricant and also leads to lower co-efficient of friction. Sputtering process was used for TiN coating on cutting tool inserts and thickness was maintained as 3 to 4 μm. Fig. 9 shows SEM image of coated inserts. In this work, nano cutting fluids were formulated by mixing nanoparticles, typically less than 100 nm in size, into a base fluid. In this study, Al_2O_3 (alumina) nanoparticles were chosen due to their better properties, and sunflower oil was selected as the base fluid because of its high viscosity, high flash point, and excellent dispersing properties. A 0.5% volume concentration of nanoparticles was added to the base fluid. To ensure a uniform distribution, the nanofluid was stirred well.

Fig. 10 indicates the samples after machining process. Surface roughness of the machined area was obtained by SJ 210 roughness tester. Average value R_a can be defined as deviation of roughness profile with integral value. Generally, it can be obtained from three different place of machined area and its average. Power consumption is the multiplication of main cutting force and its cutting velocity. Selection of cutting force device and its accuracy plays a vital role in measurement of actual cutting force involved during machining.

Fig. 4: Electric Discharge Drilling (EDD) and LASER source

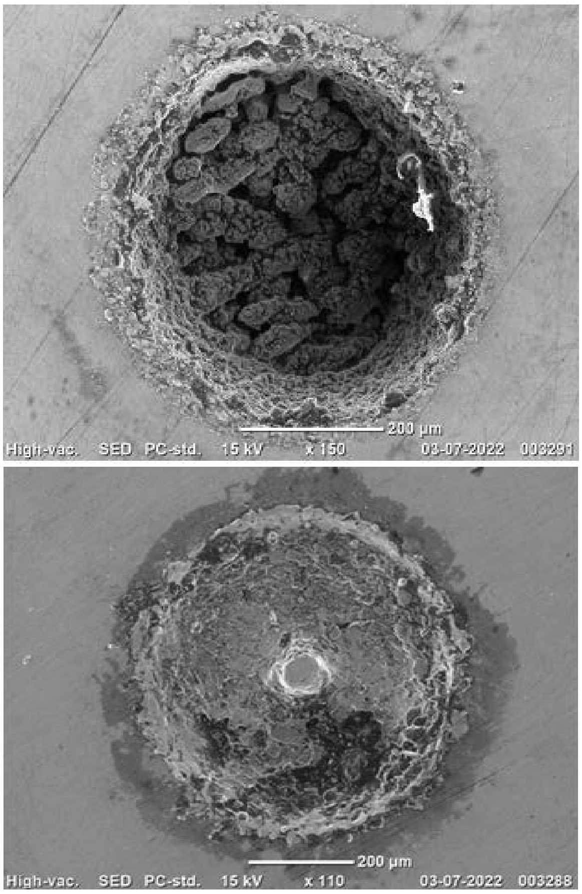

Fig. 5: SEM image of EDD and LASER produced microhole texture

Table 3. Process parameters and their levels

Parameters /Levels	Level 1	Level 2	Level 3
Cutting speed in m/min	73	104	135
Feed rate in m/rev	0.08	0.12	0.16
Depth of cut	0.3	0.6	0.9

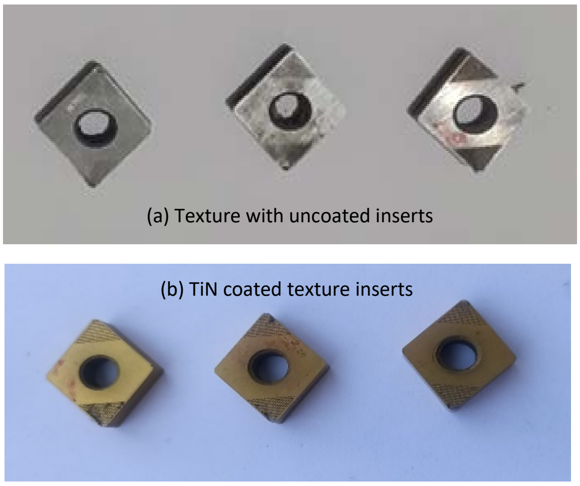

Fig. 6: Cutting inserts with micro-hole

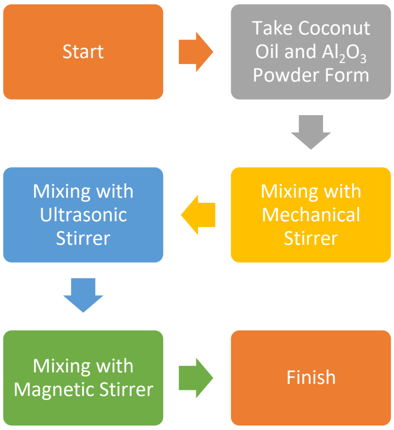

Fig. 7: Nano-fluid preparation process

Fig. 8: CNC setup with solid lubrication supply system

A power quality analyzer was used to measure the power consumed while machining. This was directly connected with power panel board and while machining. Fig. 11 shows surface roughness tester and power quality analyzer.

Table 4 shows the experimental results obtained using L_9 orthogonal matrix. Effects on each output parameter were plotted and the results were analysed (Fig. 12 and 13). Textured cutting inserts with solid lubrication was achieved using a specially designed and fabricated device. TiN coated textured cutting inserts with dry machining and cryogenic treatment on textured inserts was performed to overcome the difficulties of solid lubrication. The results were compared with textured inserts with solid lubrication, textured inserts with TiN coated textured inserts and textured inserts with nano cutting fluid environment.

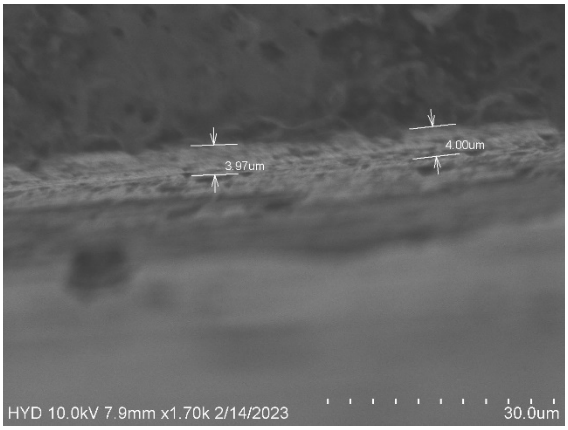

Fig. 9: SEM image of coated inserts

Table. 4. Experimental results

S. No.	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)	Texturing with solid lubrication		Texturing with ceramic (TiN) coated		Texturing with Nano Fluid	
				Surface roughness in µm	Power in kW	Surface roughness in µm	Power in kW	Surface roughness in µm	Power in kW
1	73	0.08	0.3	1.82	0.182	1.75	0.176	1.48	0.141
2	73	0.12	0.6	2.03	0.196	1.95	0.186	1.58	0.134
3	73	0.16	0.9	2.21	0.242	2.17	0.227	1.74	0.188
4	104	0.08	0.6	1.64	0.143	1.61	0.138	1.21	0.094
5	104	0.12	0.9	1.73	0.153	1.62	0.147	1.34	0.112
6	104	0.16	0.3	1.81	0.168	1.74	0.156	1.28	0.111
7	135	0.08	0.9	1.59	0.131	1.53	0.126	1.02	0.085
8	135	0.12	0.3	1.66	0.141	1.59	0.131	1.18	0.096
9	135	0.16	0.6	1.73	0.156	1.67	0.142	1.19	0.091

Fig. 10: Samples after machining process

Fig. 11: Surface roughness tester and power quality analyzer

3. RESULTS AND DISCUSSION

In this study, surface roughness and power consumption are considered as output parameters. Surface texturing on cutting tool inserts is available with different pattern. Machining performance is significantly influenced by types of texture pattern. The different patterns are micro hole, parallel, elliptical, perpendicular and cross type. During metal cutting chip flow is difficult to assume, hence micro hole type textures are advantageous in terms of not direction dependent than other type of textured pattern. It has other advantages of aerodynamic lubrication effect in between the tool-chip interface and leads to anti-adhesion effects. Hence, good machining performance is observed due to minimum tool-chip contact length and less friction.

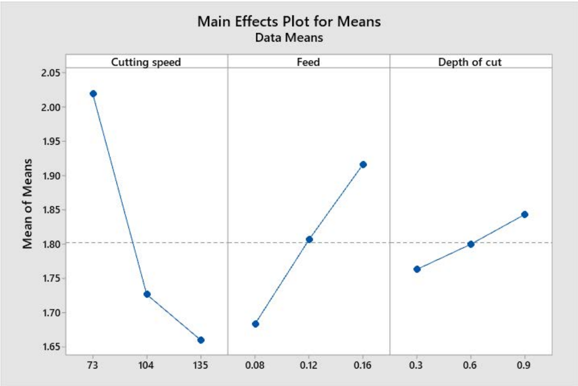

Fig. 12: (a) Surface roughness under solid lubrication

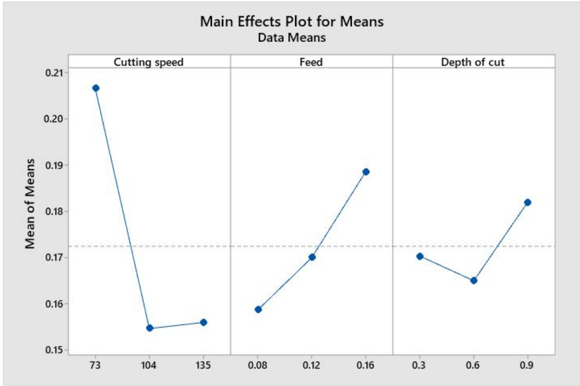

Fig. 13: (a) Power consumption under solid lubrication

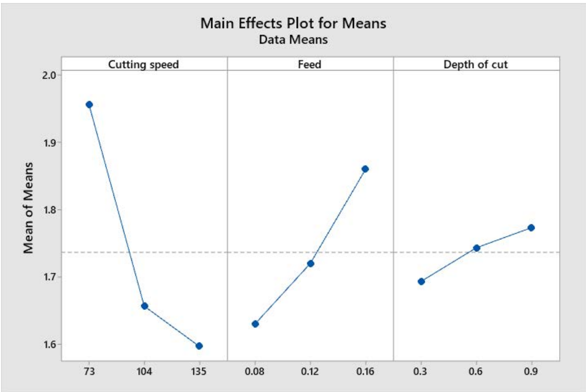

Fig. 12: (b) Surface roughness under ceramic coating

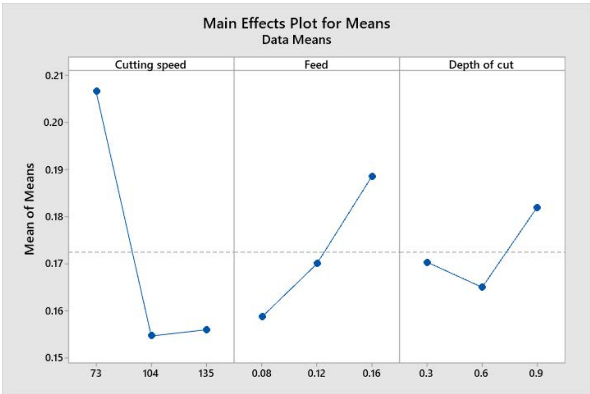

Fig. 13: (b) Power consumption under ceramic coating

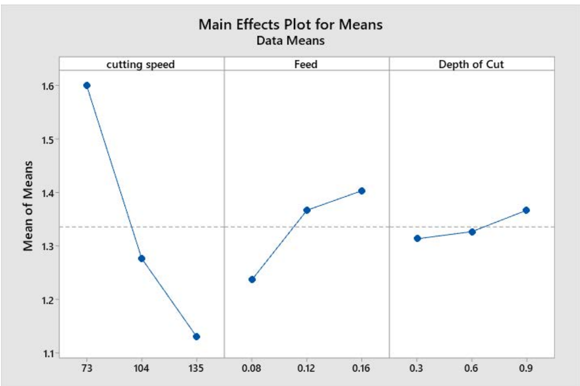

Fig. 12: (c) Surface roughness on using nano cutting fluid

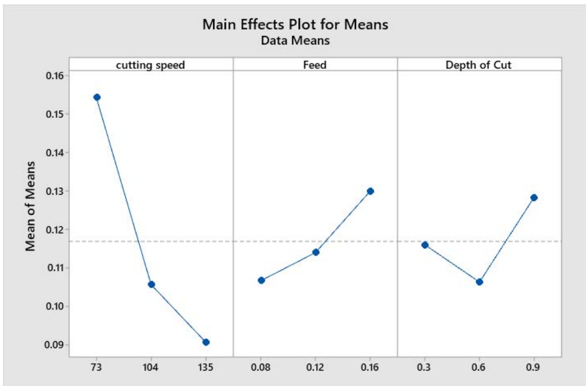

Fig. 13: (c) Power consumption on using nano cutting fluid

Solid lubrication is an alternative method. Generally, a solid lubricant is a dry powder which generates a thin lubrication film at the point of frictional heat (Sliney, 1982). TiN coating was used to reduce temperature during machining in tool-chip interface. It is noticed that, TiN coated cutting inserts provide good surface finish than solid lubrication due to its minimum coefficient of friction and good wear resistance properties. Micro hole textured insert acts as chip breaker and creates high localized pressure during chip flow. This can reduce the cutting force during machining process. Reduced power consumption values are noticed with micro hole textured inserts. From the experimental results, it is understood that textured inserts with TiN coating enhances dry machining effectively.

A nano cutting fluid was developed by blending Al_2O_3 nanoparticles with sunflower oil. This resulted in improved thermal conductivity, heat transfer coefficient, viscosity, as well as higher flash and fire points compared to the base fluid. It can also enhance tribological properties by promoting ball-like interactions between the contact surfaces. Al_2O_3 nanoparticles are hexagonally packed crystalline materials known for their high hardness, wear resistance, and heat resistance. As a result, they exhibit excellent lubricity through their anti-friction and anti-wear properties.

4. CONCLUSIONS

The problems associated with textured cutting inserts were addressed using solid lubrication, TiN ceramic coatings and nano cutting fluids, of which nano fluids outperform both TiN coatings and solid lubrication. TiN-coated textured inserts reduce surface roughness by 12%-20% and lower power consumption, while nano cutting fluids in a cryogenic environment decrease roughness by 7%-10% and power usage by 9%-20%. Solid lubricants, despite their superior lubrication, adhesive properties, and low friction, face challenges in effective delivery to the cutting zone. TiN coatings provide benefits such as enhanced lubricity, hardness, and thermal stability, while natural vegetable oil serves as an eco-friendly lubricant, and Al_2O_3 nano powder is a cost-effective option with excellent tribological properties.

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CONFLICT OF INTEREST

The authors declared no conflict of interest in this manuscript regarding publication.

REFERENCES

Amato, I. and Martinengo, P. C., Some Improvements in Solid Lubricants Coatings For High Temperature Operations, *A. S. L. E. Trans.*, 16(1), 42–49(1973). https://doi.org/10.1080/05698197308982703

Debnath, S., Reddy, M. M. and Yi, Q. S., Environmental friendly cutting fluids and cooling techniques in machining: a review, *J. Cleaner Prod.*, 83, 33–47(2014). https://doi.org/10.1016/j.jclepro.2014.07.071

Dinesh, S., Senthilkumar, V., Asokan, P. and Arulkirubakaran, D., Effect of cryogenic cooling on machinability and surface quality of bio-degradable ZK60 Mg alloy, *Mater. Des.*, 87, 1030–1036(2015). https://doi.org/10.1016/j.matdes.2015.08.099

Divya, Ch., Suvarna, R. L., Singaravel, B. and Niranjan, T., Performance investigation of micro hole textured cutting inserts on power consumption and its measuring methodology in turning process, *Alexandria Eng. J.*, 61(4), 3125–3130(2022). https://doi.org/10.1016/j.aej.2021.08.043

Laghari, R. A., Jamil, M., Laghari, A. A., Khan, A. M., Akhtar, S. S. and Mekid, S., A critical review on tool wear mechanism and surface integrity aspects of SiCp/Al MMCs during turning: prospects and challenges, *Int. J. Adv. Manuf. Technol.*, 126(7), 2825–2862(2023). https://doi.org/10.1007/s00170-023-11178-7

Lawal, S. A., Choudhury, I. A. and Nukman, Y., Application of vegetable oil-based metalworking fluids in machining ferrous metals—A review, *Int. J. Mach. Tools Manuf.*, 52(1), 1–12(2012). https://doi.org/10.1016/j.ijmachtools.2011.09.003

Lian, Y., Deng, J., Yan, G., Cheng, H. and Zhao, J., Preparation of tungsten disulfide (WS2) soft-coated nano-textured self-lubricating tool and its cutting performance, *Int. J. Adv. Manuf. Technol.*, 68(9), 2033–2042(2013). https://doi.org/10.1007/s00170-013-4827-y

Mishra, S. K., Ghosh, S. and Aravindan, S., Characterization and machining performance of laser-textured chevron shaped tools coated with AlTiN and AlCrN coatings, *Surf. Coat. Technol.*, 334, 344–356 (2018). https://doi.org/10.1016/j.surfcoat.2017.11.061

Rahman, S. S., Ashraf, M. Z. I., Amin, A. K. M. N., Bashar, M. S., Ashik, M. F. K. and Kamruzzaman, M., Tuning nanofluids for improved lubrication performance in turning biomedical grade titanium alloy, *J. Cleaner Prod.*, 206, 180–196(2019). https://doi.org/10.1016/j.jclepro.2018.09.150

Saikrupa, Ch., Reddy, G. C. and Venkatesh, S. (2022). Experimental investigation of cutting conditions in turning of Al-MMC, *Mater. Today Proc*., 76, 488-494 (2023). https://doi.org/10.1016/j.matpr.2022.11.154

Saini, P. and Singh, P. K., Characterization and optimization analysis on surface finish and energy consumption in turning of Al-4032/GMP MMC produced by stir casting, *Proc. Inst. Mech. Eng., Part C: J. Mech. Eng. Sci.*, 236(24), 11549–11563(2022). https://doi.org/10.1177/09544062221110475

Sharma, V. S., Singh, G. and Sørby, K., A Review on Minimum Quantity Lubrication for Machining Processes, *Mater. Manuf. Processes*, 30(8), 935–953(2015). https://doi.org/10.1080/10426914.2014.994759

Singaravel, B. and Selvaraj, T., Experimental Investigation on Cutting Forces, Specific Cutting Pressure, Co-Efficient of Friction and Shear Energy in Turning of HSLA Steel, *Manage. Prod. Eng.*, 7(1), 71-76 (2016). https://doi.org/10.1515/mper-2016-0008

Sliney, H. E., Solid lubricant materials for high temperatures—a review, *Tribol. Int*., 15(5), 303–315(1982). https://doi.org/10.1016/0301-679X(82)90089-5

Tannous, J., Dassenoy, F., Lahouij, I., Le Mogne, T., Vacher, B., Bruhács, A. and Tremel, W., Understanding the Tribochemical Mechanisms of IF-MoS2 Nanoparticles Under Boundary Lubrication, *Tribol. Lett.*, 41(1), 55–64(2011). https://doi.org/10.1007/s11249-010-9678-1

Krishna. P.V. and Rao. D. N., Performance evaluation of solid lubricants in terms of machining parameters in turning, *Int. J. Mach. Tools Manuf*., 48(10), 1131–1137(2008) https://doi.org/10.1016/j.ijmachtools.2008.01.012

Zhang, K., Deng, J., Ding, Z., Guo, X. and Sun, L., Improving dry machining performance of TiAlN hard-coated tools through combined technology of femtosecond laser-textures and WS2 soft-coatings, *J. Manuf. Processes*, 30, 492–501(2017). https://doi.org/10.1016/j.jmapro.2017.10.018

Zhang, S. and Zhu, W., TiN coating of tool steels: a review, *J. Mater. Process. Technol*., 39(1), 165–177(1993). https://doi.org/10.1016/0924-0136(93)90016-Y

Zhou, C., Guo, X., Zhang, K., Cheng, L. and Wu, Y., The coupling effect of micro-groove textures and nanofluids on cutting performance of uncoated cemented carbide tools in milling Ti-6Al-4V, *J. Mater. Process. Technol.*, 271, 36–45(2019). https://doi.org/10.1016/j.jmatprotec.2019.03.021