Tuijin Jishu/Journal of Propulsion Technology
ISSN:1001-4055
Vol. 44No. 4 (2023)

Enhancing Sustainability in Machining: Performance Evaluation of Graphene-Based Green Cutting Fluids in Minimum Quantity Lubrication (MQL) Turning

JavvadiEswara Manikanta[1,2*], B.Naga Raju[3]

[1]Research scholar in Trans-Disciplinary Research Hub, Andhra University, Visakhapatnam, Andhra Pradesh, India
[2]Department of Mechanical Engineering, Shri Vishnu Engineering College for Women(A), Bhimavaram, India
[3]Department of Mechanical Engineering, Anil Neerukonda Institute of Technology and Sciences(A), Visakhapatnam, Andhra Pradesh, India

Abstract: This study explored the performance of a new type of graphene based green cutting fluids in minimum quantity lubricationmachiningprocess helps in sustainability through ecofriendly machining processes. The effectiveness of green cutting fluids nano-graphene with varying concentrations 0.4%, 0.8%, 1.2%, 1.6% and 2% isevaluated in turning process with minimum quantity lubrication. The machining carried out within the context of dry, wet, minimum quantity lubrication, and nano minimum quantity lubrication environments. Comparative study was carried out to analyse cuttingforce, temperatureand surface roughness inmachiningoperation with graphene nanofluids. The findings reveal a momentousdecrease in cutting force, cutting temperature, and surface roughness about 18.98%, 31.74%, and 24.23%, respectivelywhen utilizing 1.6% graphenenanofluids as compared to conventional coolants during wet machining. These results emphasize the promising potential of graphene-based green cutting fluids in enhancing the sustainability of machining processes, contributing to eco-friendly manufacturing practices.

Keywords:*Cutting force, Eco-friendly machining, Graphene-based green cutting fluids, Minimum quantity lubrication, Surface roughness, Sustainability.*

1. Introduction

Normally Petroleum based cutting fluids are used in turning to decrease friction and improvemetal cutting operation performance by lubrication effect and cooling[1] . On the other hand, the utilization of cutting fluids is reason for environment damage and negative impact on workers' healthdue to these are mostly petroleum based oils[2]. Therefore, there is a contemporary necessity to establish an environmentally sustainable manufacturing approach through the elimination of conventional cutting fluids [3]. In this context, the utilization of a minimal quantity of lubricant can be considered an economically viable and environmentally friendly substitute for machining[4]. In this direction, the optimal path is the implementation of minimum quantity lubrication (MQL), a method where a precisely measured lubricant mixture is directed to machining area using compressed air[5]. This approach minimizes the usage of cutting fluid while enhancing machining capabilities[6]. Vegetable oils mixing with nanoparticles exhibiting good machining characteristics with no health hazardous and environment pollution[7]. The performance of graphene nano Cutting Fluids The evaluation during the machining process revealed smooth surface and decreased tool wear [8].Sayuztiet al. [9] investigated machining by nano SiO_2 lubrication system. In that they obtained improved machining performance compared to conventional lubrication[10]. Better performance of MQL during grinding of ceramics was reported by Emami M et al.[11]. The eco friendly vegetable oil with MQL technique was utilized in Inconel material machining operation. The outcomes were shown in increasing surface finish, and the tool life[12]. In certain studies, the investigation of different vegetable oils, sunflower, and neem, as cutting fluids in metal cutting operations was conducted. These studies reported enhanced machining process attributes when employing vegetable based fluids with the MQL technique[13]. In this work investigated effect ofnano additives added vegetable oils in metal cutting process. Throughout machining operations, temperature of tip of tools increases and leads high tool wear, causing down time of machines in due to change cutting tools. To increase tool life phenomenon and unnecessary workpiece heating, several actions can be used and the best one is selection of an suitable cutting fluid and lubrication method[14].In some works found that the superior heat extraction and wettability of fluid mixture with various nanoparticles in fluid [15]. Therefore, it is possible to enhance both heat dissipation and lubrication within the cutting zone by using nanoparticles with base fluid in machining operation. Estelle P et al.[16]investigated water based carbon nanotubes during the thermal properties testing and the results were found that thermal conductivity and viscosity enhanced in nano fluids. In another study dry, conventional and MQL method assessed during machining of hardened steel by Mia M et al.[17]. Performance was analyzed by measuring cutting force. A noticeable decrease in cutting force was observed compared to the MQL method. Some studies found that result of extreme pressure additives in vegetable based lubricants, effect was higher rate of EP decreased cutting forces in machining of AISI 304L steel, however negative effect is also experienced that rise of EP additives causing more surface roughness. Finally, it was informed that VBCFs have the possible characteristics to substitute petroleum based dangerous cutting fluids in machining operation. Srikant et al. [18]analyzed the use of nanofluids with copper oxide additives in water based fluids in machining operation and observed significant decrease in tool tip temperature due to improved heat extraction capabilities of nanofluids. Krajnik et al. [19] examined the improvements in study on cooling and lubrication aspects of nanofluids and their possible function as cutting fluids in metal cutting operation. They inferred that accurately prepared suitable nanofluids be able to achieve superior than normal cutting fluids with respect to tribologicaol and thermal properties. Nam et al.[20]did experiments on micro drilling tests under states of compressed air lubrication, pure MQL with vegetable oil, and nano diamond particles added vegetable oil minimum quantity lubrication. The results demonstrated that the incorporation of nano diamond particles into vegetable oil for MQL yielded better performance compared to pure vegetable oil MQL. In the case of nano diamond particle-infused vegetable oil MQL, the optimal nanodiamond additive ratio is 2.0 vol% for improving drilling process performance.Park et al.[21]Performed experiments in milling process with MQL system by nanoparticles and stated that nano graphene additive (GnP)-enhanced vegetable oil presented improved performance than vegetable oil. In addition to that, the optimal ratio of GnP for the enhancement of machining operation was 0.1 wt%. Sharma et al. [22] to improve the machining characteristics of minimum quantity lubrication, particularly for ultra hard materials, various developments in MQL have been applied in research, i.e., nanofluid with of minimum quantity lubrication. J E Manikanta et al [23] investigated on effect of effect of nano cutting fluid in machining of SS304 Alloy. Their findings indicated that the material removal rate (MRR) is primarily impacted by the depth of cut and the weight percentage (wt. %) of the Nano cutting fluid. Moreover, the surface finish was found to be influenced by the wt. % of the Nano cutting fluid and the cutting speed. The performance of vegetable oilmixednanofluid under MQL grinding of Nikel-Cr Alloy was done by Virdi et al. [24]. Nano CuO with 0.5and 1 wt % in base oils was mixed to prepare the nanofluids. A noteworthy increment in surface finish and the reduced temperature was found with MQL technique and the polishing effects of CuO nanoparticles at the cutting area. Gaurav et al. [25]studied the effectiveness of jojoba-based oil and a mixture of jojoba oil with nanoparticles for machining Titanium using minimum quantity lubrication. They assessed nanofluid MQL performance across various nanoparticle ratios. The results highlighted significant reductions in machining output parameters, attributing these improvements to the superior cooling and lubrication capabilities of the nanofluid MQL.This paper discussed the turning of stainless steel with TiAlN coated carbide insert by using different types of Gr nanofluids in green cutting fluid with the concentrations of 0.4%, 0.8%, 1.2%, 1.6% and 2% respectively. Experiments were conducted involving dry, wet, MQL, and nMQL cutting techniques, each utilized with different levels of Gr concentration. The parameters studied included cutting forces, cutting temperatures, and surface roughness. Comparative analysis of machining performances between different cutting fluids and machining environments were conducted.

2. Experimentation

2.1. Experimental conditions and procedure

Stainless steel bar (SS304) with the dimension of 200 mm length with 50 mm diameter was used as workpiece.Insert SNMG 120408NSUand tool holder PSBNR2525M-12 was used for the experimental investigations. The machining experiments were carried out on Turn master 35 lathe machine (Kirloskar make). Input parameters of lathe machine cutting speed 1000 rpm, feed of 90 mm/min, and depth of cut 0.45 mm as set by the standard set of machine specifications.The experiments were done under dry, wet, MQL, and nMQLenvironments.The wet machining approach involved employing a commercially accessible conventional cutting fluid (CCF) at a flow rate of 45 L/hr. Meanwhile, the Minimum Quantity Lubrication (MQL) method utilized a small volume of cutting fluid applied at a flow rate of 500 mL/hr.As mentioned earlier, the 0.4%, 0.8%, 1.2%, 1.6% and 2% concentration of nano-graphene in corn based green cutting fluid was used for the MQL machining. A Mitutoyo SJ.201P type surface tester is taken to measure the average surface roughness (R_a) of workpiece after the experimentation and the cut-off length, sampling number are set as 0.8mm, 5 respectively. The temperature existed at the tip of selected cutting tool during a successful turning operation is measured by a digital pyrometer with a lowest recording capacity of 0.1^{0}C. The assessment of cutting force was conducted by a piezoelectric dynamometer, Kistler 9257B model.

2.2. Nanofluid preparation

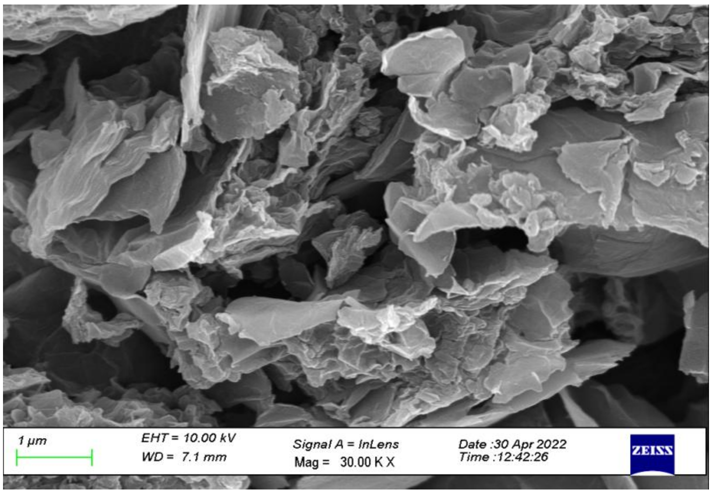

Figure 1. FESEM image of graphene nanoparticles

In this study corn-based green cutting fluid(GCF) was used as base fluid[26]. The nanofluid was prepared by dispersing graphene nanopowder in corn based green cutting fluid as base fluid. The nanofluid was created by dispersing graphene into base oil at varying concentrations (0.4%, 0.8%, 1.2%, 1.6%, and 2% by weight). Figure 1 displays an image captured through field emission scanning electron microscopy of graphene nanoparticles.To ensure a uniform mixture of graphene nanoparticles within the base fluid, an ultrasonic vibrator operating at 40 kHz and 100 W was employed. To enhance the stability of dispersion and prevent nanoparticle clustering in the base oil, a small quantity of Lauryl sodium sulphate (SDS), equivalent to 0.1% of the graphene weight, was introduced. Fig. 2 shows the schematic presentation of MQL machining with nanofluids.

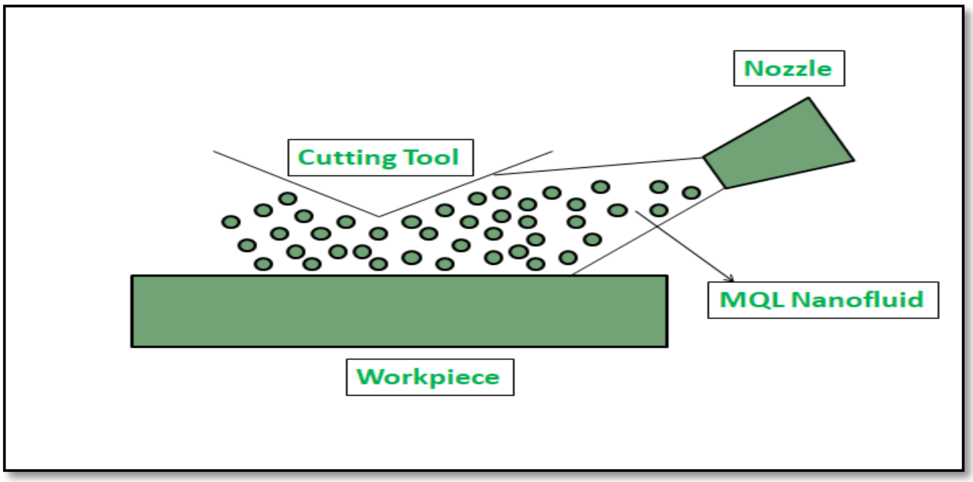

Fig. 2 Schematic presentation of MQL machining with Nanofluids

3. Results and Discussion

3.1 Cutting Force

High cutting forces cause rapid tool wear, reducing the tool lifespan, increasing the frequency of tool changes and also poor surface finish due to vibration and chatter during machining. Fig. 3 shows the measured cutting force under several turning conditions under dry, conventional, MQL and nMQL with different types of cutting fluids, which are CCF,GCF, GCF with Gr with concentrations of 0.4 wt. % Gr, 0.8 wt.% Gr , 1.2 wt.% Gr , 1.6 wt.% Gr and 2 wt.% respectively. In dry condition the highest cutting force developed by 133.8N due to not have lubricating media.Cutting force generated in wet machining with CCF cutting is 105 N. The cutting force produced in MQL machining with GCF cutting is 102.3N. In MQL machining cutting force decreased when Gr nanofluids were applied.

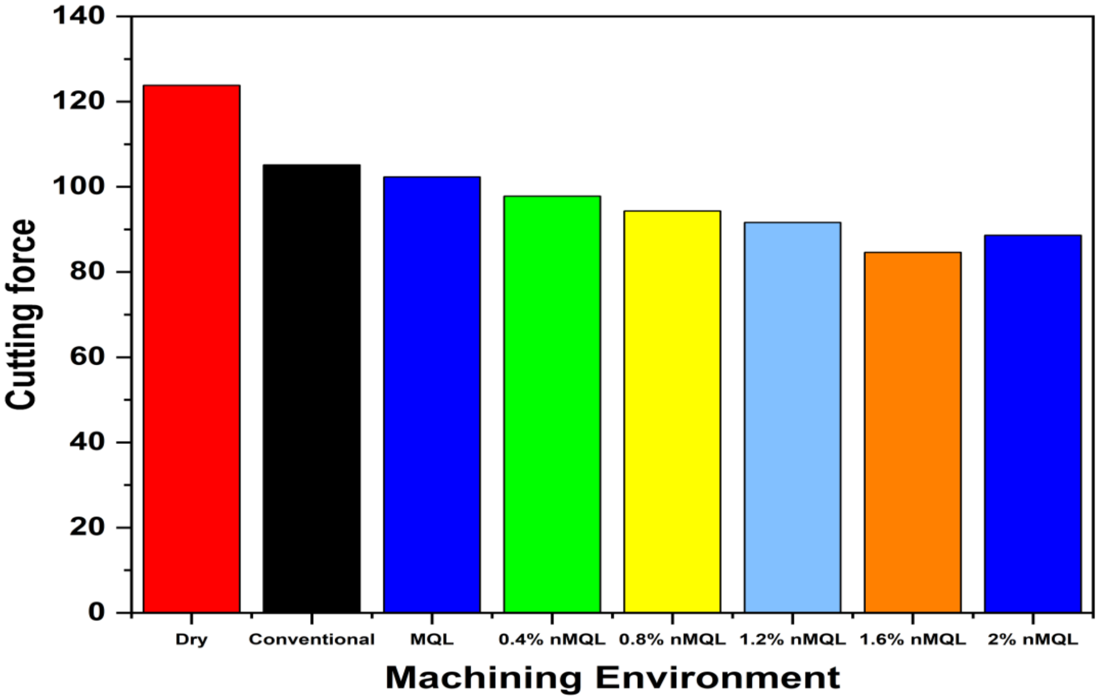

Fig. 3Cutting forces with different machining environment

Applying 0.4 wt.% Gr nanofluids reduced cutting force at the machining zone by 97.8N. Increasing Gr concentration to 0.8 wt.%, 1.2 wt.%, and 1.6 wt.% led to decreasing forces of 94.3 N, 91.6 N, and 84.6N, respectively, compared to 0.4 wt.% concentration. This drop in cutting force resulted from improved lubrication. Nanoparticles on the metal surface created a durable lubricant film, enhancing heat dispersion. Greater thermal conductivity and lubrication from higher Gr concentration reduced friction, heat generation. In case of, at 2 wt.%, cutting force was 88.6N higher than at 1.6 wt.% due to nanoparticle agglomeration, which impaired nanofluid performance.

3.2 Cutting Temperature

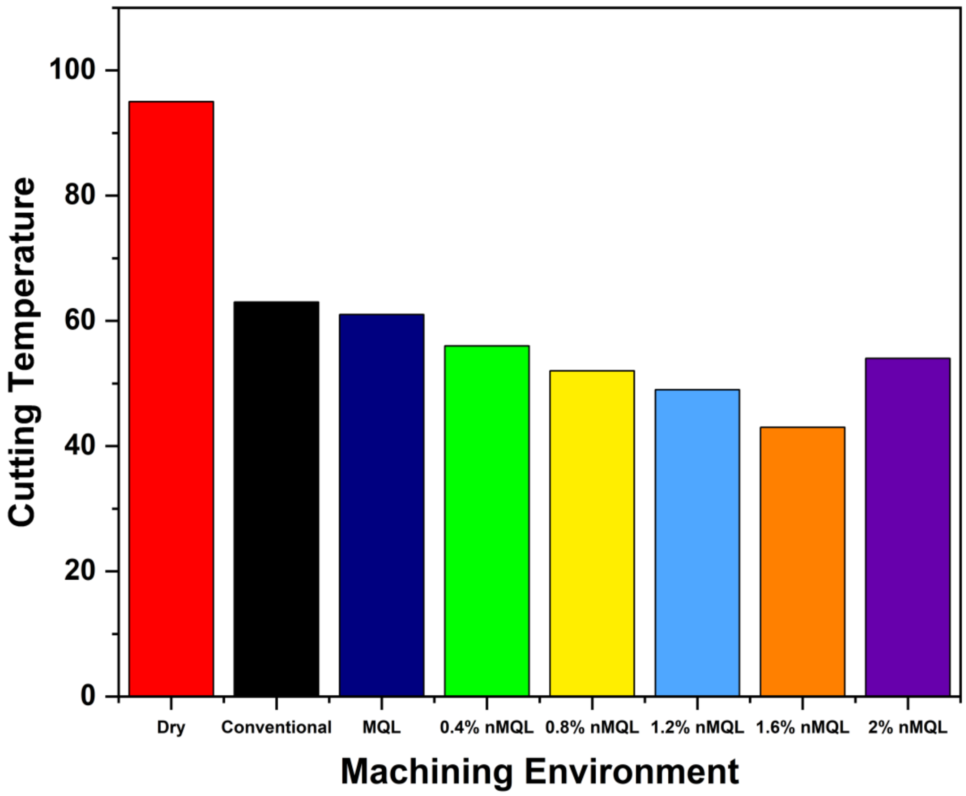

Fig. 4Cutting temperature with different machining environment

Higher cutting temperatures expedite the deterioration of the cutting tool, cause tool materials to soften, wear down, leading to reduced tool life.High cutting temperatures can negatively affect surface finish. Extreme cutting temperatures can cause changes in the workpiece material microstructure due to heat generated in the cutting process. This can affect properties of workpiece such as hardness, tensile strength, residual stresses.Fig. 4Depicts the recorded cutting temperatures for various turning conditions under dry, conventional, MQL and nMQL with different types of cutting fluids, which are CCF,GCF, GCF with Gr with concentrations of 0.4 wt.% Gr, 0.8 wt.% Gr , 1.2 wt.% Gr , 1.6 wt.% Gr and 2 wt.% respectively. In dry condition the highest cutting temperature developed by 95℃ due to not having cooling and lubricating media. The cutting temperature generated in wet machining with CCF cutting is 63 ℃. The cutting temperature generated in MQL machining with GCF cutting is 61 ℃. In MQL machining cutting temperature decreased when Gr nanofluids were applied.Enhanced cooling effects of graphene (Gr) nanofluids were clearly evident based on the temperature measurements obtained from the cutting experiments. When utilizing 0.4 wt.% Gr nanofluids, a substantial reduction of 56°C in temperature was observed at interface between tool and chip. As the concentration of Gr increased to 0.8 wt.%, 1.2 wt.%, and 1.6 wt.%, the corresponding decreases in cutting temperature were 52°C, 49°C, and 43°C, respectively, in comparison to the 0.4 wt.% Gr nanofluid application. This reduction in cutting temperature was primarily attributed to the combined effects of improved lubrication and enhanced thermal conductivity. Nanoparticles present along metal surface formed robust and enduring lubricant film. Another, the heightened thermal conductivity resulting from the exceptional thermal properties of the graphene oxide particles facilitated the dissipation of more heat. On the other hand, the elevated concentration of Gr led to more effective lubrication, which consequently reduced friction and the associated heat generation from frictional forces. However, during the cutting process employing a 2 wt.% concentration of Gr nanofluids, the cutting temperature was 54°C higher compared to the scenario where the Gr concentration was 1.6 wt.%. This divergence was due to agglomeration of nanofluid concentration, which in turn compromised the performance of the nanofluids.

3.3 Surface Roughness

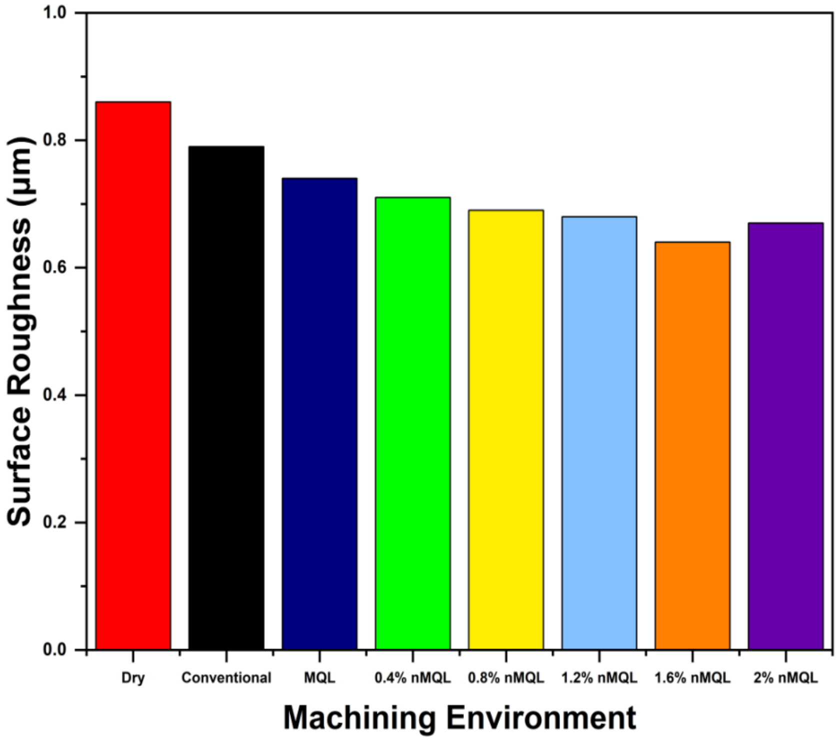

Fig. 5 Cutting temperature with different machining environment

Surface roughness directly affects the visual and quality of the finished product. Smoother surfaces are generally preferred for better aesthetics. Rough surfaces provide more crevices for moisture and corrosive agents to accumulate, potentially accelerating corrosion. Surface roughness can act as a stress concentration point, potentially reducing the fatigue strength of the component. Fig.5 shows the measured surface roughness under different turning conditions under dry, conventional, MQL and nMQL with different types of cutting fluids, which are CCF,GCF, GCF with Gr with concentrations of 0.4 wt. % Gr, 0.8 wt.% Gr , 1.2 wt.% Gr , 1.6 wt.% Gr and 2 wt.% respectively. In dry condition the highest surface roughness developed by 0.86μm due to absence of cooling and lubricating media.The surface roughness generated in wet machining with CCF cutting is 0.79μm. The surface roughness generated in MQL machining with GCF cutting is 0.74μm. In MQL machining surface roughness decreased when Gr nanofluids were applied. The cutting experiments revealed significant improvements in cooling and lubrication when using Gr nanofluids. When 0.4 wt.% Gr nanofluids were employed, a reduction of 0.71μm in surface roughness was observed. Furthermore, with increasing Gr concentrations to 0.8 wt.%, 1.2 wt.%, and 1.6 wt.%, the surface roughness showed corresponding reductions of 0.69μm, 0.68μm, and 0.64μm, respectively, compared to the 0.4 wt.% Gr nanofluid. The combination of improved lubrication and heightened thermal conductivity primarily contributed to the decrease in surface roughness. The nanoparticles formed a robust and enduring lubricant film on the metal surface. The enhanced thermal conductivity, credited to the exceptional thermal properties of graphene oxide particles, effectively dissipated more heat. On the other hand, the increased lubrication resulting from a higher concentration of graphene (Gr) led to reduced friction, thus minimizing heat generated by friction forces. During the cutting process, when the graphene concentration was at 2 wt.%, the surface roughness increased to 0.67µm compared to the 1.6 wt.% Gr concentration. This disparity is due to the agglomeration of nanofluids at higher concentrations, which negatively impacted their performance.Fig.6 shows the flank tool wear in different lubrication environments.

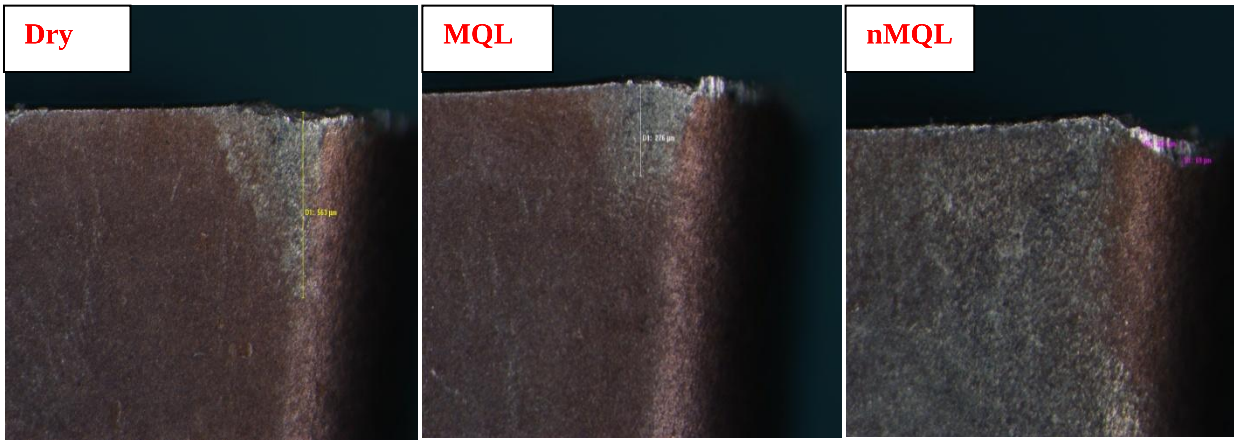

Fig. 6 Tool wear with different machining environment

4. Conclusions

The current study explores the efficiency of a corn-based eco-friendly cutting fluid infused with different levels of graphene during the machining process of SS 304. A comparative analysis is conducted between these findings and the outcomes from dry, wet, and MQL assisted machining techniques. The ensuing observations can be succinctly outlined according to the achieved results.

(1) The corn based green cutting fluid added with varying concentrations of graphene (0.4%, 0.8%, 1.2%, 1.6% and 2%) enhanced machining performance has been achieved under the given circumstances.

(2) The anticipated enhancement in surface finish is achieved by employing environmentally friendly corn-based cutting fluid along with nano graphene. The least surface roughness occurs at a graphene concentration of 1.6%. However, greater concentrations of 2% lead to elevated surface roughness due to increased viscosity and the clustering of nanoparticles within the cutting fluid mixture.

(3) The utilization of nMQL showed a decrease in cutting force and cutting temperature, resulting in an extended tool lifespan when employing corn-based eco-friendly cutting fluid infused with nano graphene. The most minimal cutting force and cutting temperature occurs when using a 1.6% graphene concentration within the corn-based cutting fluid. This is attributed to the improved lubricating capacity of graphene, which effectively penetrates the interfaces between the work-tool and chip-tool.

The findings demonstrated the efficacy of utilizing nanofluid derived from vegetable oil in Minimum Quantity Lubrication (MQL) for machining SS 304. This approach led to improved machinability, as evidenced by enhanced surface finish.

5. References

[1] Y. Song, H. Cao, D. Qu, H. Yi, X. Kang, X. Huang, J. Zhou &C. Yan, Surface integrity optimization of high speed dry milling UD-CF/PEEK based on specific cutting energy distribution mechanisms effected by impact and size effect, *J. Manuf. Process.* 79 (2022) 731–744. https://doi.org/10.1016/j.jmapro.2022.05.024.

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

[3] J.E. Manikanta, B.N.V.S. Ganesh Gupta, J.T. Manikanta& R. Pradeep, Integrality characterization of machining with nano cutting fluids, *Int. J. Mech. Eng. Technol.* 9 (2018) 1033–1042.

[4] G.R. Singh &V.S. Sharma, Analyzing machining parameters for commercially puretitanium (Grade 2), cooled using minimum quantity lubrication assisted by a Ranque-Hilsch vortex tube, *Int. J. Adv. Manuf. Technol.* 88 (2017) 2921–2928. https://doi.org/10.1007/s00170-016-8982-9.

[5] J.E. Manikanta, B.N. Raju, R. Bhadri & R. Chekuri, Performance assessment of nano alumina mixed corn oil in stainless steel, *European Chemical Bulletin*.12 (2023) 5723–5734. https://doi.org/10.31838/ecb/2023.12.8.456.

[6] K.K. Gajrani &M.R. Sankar, Sustainable Cutting Fluids : Thermal , Rheological , Biodegradation , Anti-Corrosion , Storage Stability Studies and its Machining Performance, *Elsevier* Ltd., 2018. https://doi.org/10.1016/B978-0-12-803581-8.11152-X.

[7] E. Kuram, B. Ozcelik, E. Demirbas &E. S, I.N. Tansel, Evaluation of New Vegetable-Based Cutting Fluids on Thrust Force and Surface Roughness in Drilling of AISI 304 Using Taguchi Method Evaluation of New Vegetable-Based Cutting Fluids on Thrust Force and Surface Roughnes, *Materials and Manufacturing Processes*, 13(2019) 37–41. https://doi.org/10.1080/10426914.2010.536933.

[8] M.K. Gupta, Q. Song, Z. Liu, M. Sarikaya, M. Jamil, M. Mia, A.K. Singla, A.M. Khan, N. Khanna &D.Y. Pimenov, Environment and economic burden of sustainable cooling/lubrication methods in machining of Inconel-800, *J. Clean. Prod.* 287 (2021) 125074. https://doi.org/10.1016/j.jclepro.2020.125074.

[9] M. Sayuti, A.A.D. Sarhan &F. Salem, Novel uses of SiO2 nano-lubrication system in hard turning process of hardened steel AISI4140 for less tool wear, surface roughness and oil consumption, *J. Clean. Prod.* 67 (2014) 265–276. https://doi.org/10.1016/j.jclepro.2013.12.052.

[10] S. Yi, J. Mo &S. Ding, Experimental investigation on the performance and mechanism of graphene oxide nano fl uids in turning Ti-6Al-4V, *J. Mfg. Proc.*43 (2019) 164–174. https://doi.org/10.1016/j.jmapro.2019.05.005.

[11] M. Emami, M.H. Sadeghi, A.A.D. Sarhan & F. Hasani, Investigating the Minimum Quantity Lubrication in grinding of Al 2O3 engineering ceramic, *J. Clean. Prod.* 66 (2014) 632–643. https://doi.org/10.1016/j.jclepro.2013.11.018.

[12] L. Gong, R. Bertolini, A. Ghiotti, N. He &S. Bruschi, Sustainable turning of Inconel 718 nickel alloy using MQL strategy based on graphene nanofluids, *Int. J. Adv. Manuf. Technol.* 108 (2020) 3159–3174. https://doi.org/10.1007/s00170-020-05626-x.

[13] M.A. Makhesana &K.M. Patel, Performance assessment of vegetable oil-based nanofluid in Minimum Quantity Lubrication (MQL) during machining of Inconel 718 Performance assessment of vegetable oil-based nanofluid in, *Adv. Mater. Process. Technol.* (2021) 1–17. https://doi.org/10.1080/2374068X.2021.1945305.

[14] M. Sandeep Kumar &V. Murali Krishna, An Investigation on Turning AISI 1018 Steel with Hybrid

Biodegradeable Nanofluid/MQL Incorporated with Combinations of CuO-Al2O3 Nanoparticles, *Mater. Today Proc*. 24 (2020) 1577–1584. https://doi.org/10.1016/j.matpr.2020.04.478.

[15] P. Rapeti, V.K. Pasam, K.M. Rao Gurram &R.S. Revuru, Performance evaluation of vegetable oil based nano cutting fluids in machining using grey relational analysis-A step towards sustainable manufacturing, *J. Clean. Prod.* 172 (2016) 2862–2875. https://doi.org/10.1016/j.jclepro.2017.11.127.

[16] P. Estellé, S. Halelfadl &T. Mare, Lignin as dispersant for water-based carbon nanotubes nanofluids: Impact on viscosity and thermal conductivity, Int. Commun. *Heat Mass Transf.* 57 (2014) 8–12. https://doi.org/10.1016/j.icheatmasstransfer.2014.07.012.

[17] M. Mia, M.K. Gupta, G. Singh, G. Królczyk &D.Y. Pimenov, An approach to cleaner production for machining hardened steel using different cooling-lubrication conditions, *J. Clean. Prod.* 187 (2018) 1069–1081. https://doi.org/10.1016/j.jclepro.2018.03.279.

[18] R.R. Srikant, D.N. Rao, M.S. Subrahmanyam, P.V. Krishna, Applicability of cutting fluids with nanoparticle inclusion as coolants in machining, *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.* 223 (2009) 221–225. https://doi.org/10.1243/13506501JET463.

[19] P. Krajnik, F. Pusavec, A. Rashid, Advances in Sustainable Manufacturing, *Adv. Sustain. Manuf.* (2011) 107–108. https://doi.org/10.1007/978-3-642-20183-7.

[20] J.S. Nam, P.H. Lee &S.W. Lee, Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication, *Int. J. Mach. Tools Manuf.* 51 (2011) 649–652. https://doi.org/10.1016/j.ijmachtools.2011.04.005.

[21] K.H. Park, B. Ewald &P.Y. Kwon, Effect of nano-enhanced lubricant in minimum quantity lubrication balling milling, *J. Tribol.* 133 (2011) 1–8. https://doi.org/10.1115/1.4004339.

[22] A.K. Sharma, A.K. Tiwari &A.R. Dixit, Effects of Minimum Quantity Lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: A comprehensive review, *J. Clean. Prod.* 127 (2016) 1–18. https://doi.org/10.1016/j.jclepro.2016.03.146.

[23] J.E. Manikanta & D.S.Rao Effect of Nano Cutting Fluid & Process Parameters on Material Removal Rate and Surface Finish of SS304 Alloy on Turning Operation,*Int. J. of Em. Tech. in Eng.Res.*5 (2017) 71–80.

[24] R.L. Virdi, S.S. Chatha &H. Singh, Processing Characteristics of Different Vegetable Oil-based Nanofluid MQL for Grinding of Ni-Cr Alloy, *Adv. Mater. Process. Technol.* (2020) 1–14. https://doi.org/10.1080/2374068X.2020.1800312.

[25] G. Gaurav, A. Sharma, G.S. Dangayach &M.L. Meena, Assessment of jojoba as a pure and nano-fluid base oil in minimum quantity lubrication (MQL) hard-turning of Ti–6Al–4V: A step towards sustainable machining, *J. Clean. Prod.* 272 (2020) 122553. https://doi.org/10.1016/j.jclepro.2020.122553.

[26] J. Eswara, B.N. Raju, C. Prasad &B.S.S.P. Sankar, Machining performance on SS304 using nontoxic , biodegradable vegetable-based cutting fluids, *Chem. Data Collect*. 42 (2022) 100961. https://doi.org/10.1016/j.cdc.2022.100961.