PERFORMANCE ASSESSMENT OF NANO ALUMINA MIXED CORN OIL IN STAINLESS STEEL MACHINING

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Abstract:

Metal material removal industries are concentrating on the development of energy efficient and sustainable metal removing operations. Current work concentrated on the usefulness of nanofluids based minimum quantity lubrication (MQL) during the turning of stainless steel alloy (SS 304).The use of corn based green cutting (CBGC) oil mixed with nano alumina (nal_2o_3) with different ratios (0.4%, 0.8%, and 1.2%) is evaluated in MQL based turning process. Dry, conventional, MQL, and nMQL (CBGC oil+ nal_2o_3) lubrication methods have been applied for machining operations. The functioning of different cutting environments is tested by using surface finish, tool wear, material removal rate and chip analysis. A notable drop in surface roughness and tool flank wear is found with 1.2% nal_2o_3 added with CBGC oil compared to other turning conditions. Also, the satisfactory chip curls are generated with nMQL and MQL cooling conditions. Based on the verdicts of the study, the nal_2o_3 mix of CBGC oil can be considered as a reasonable substitute to accomplish sustainable and eco friendly metal cutting operation.

Keywords: Machining; Nanofluids; MQL; Surface finish; Tool wear; Chip analysis.

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1. Introduction

By reducing extra material, metal cutting procedures aid in transforming semi-finished goods into finished goods. SS 304 is frequently found in machinery parts including hydraulic shafts and pump shafts[1]. Cutting fluids with a petroleum base are typically used in machining to reduce friction while enhancing the performance of metal cutting operations through lubricating and cooling[2][3]. Conversely, the use of these cutting fluids is linked to health and environmental problems because they are typically based on petroleum-based oils[4][5]. Therefore, creating a sustainable manufacturing process today requires doing away with traditional cutting fluids[6]. In this sense, using a minimal amount of lubrication during machining could be seen as a more economical and environmentally beneficial option[7]. The greatest strategy in this area is MQL (minimal quantity lubrication), which involves using compressed air to spray an ideal amount of lubricant mixture over the machining zone. It enhances machining performance while using the least amount of cutting fluid allowed[8]. Al_2O_3 nano Cutting Fluids performed well during the evaluation, resulting in a smooth surface and less tool wear[9]. By using a nano-SiO_2 lubricating system, Sayutiet al.[10] examined the hard turning process of AISI4140 hardened steel material. In contrast to standard lubrication, they achieved extremely reduced tool wear, surface roughness, and cutting fluid consumption. Emami M. et al.[11] noticed improved performance of minimal lubrication during grinding of ceramics. When turning pure titanium with coated carbide tools, Singh et al. [12] discovered the differences between dry, conventional cooling, cooling with a Ranque- Hilsch- vortex tube (RHVT), and MQL with canola oil. With better cooling and lubrication, MQL-based machining produced parts with lower tool wear and surface roughness. Following conventional machining and MQL with canola oil-assisted machining, dry machining was found to have the highest energy consumption and carbon emissions. According to certain research, MQL with vegetable base cutting fluids improved machining outputs by reducing surface roughness, reducing tool wear, and minimising cutting forces[13]. In the machining of Inconel material, environmentally friendly vegetable oil was combined with MQL process. Increases in surface quality and tool life demonstrated the results[14]. In several works, the use of different vegetable oils as cutting fluids in metal cutting operations (coconut, sunflower, neem, etc.) was explored and reported the improved machining process characteristics using vegetable based fluids with MQL technology[15][16][17]. This study looked into the effects of using vegetable oils with nano additions when cutting metal. The temperature of the tool tips rises during machining operations, which results in increased tool wear and machine downtime owing to cutting tool replacement. The ideal action is choosing an appropriate cutting fluid and lubrication strategy to reduce the phenomenon of cutting tool wear and the needless workpiece heating[18]. A few investigations discovered that fluid mixtures with different nanoparticles in them had better heat extraction and wettability[19]. Thus, by combining nanoparticles with base fluid during machining operations, high heat removal and lubrication in the cutting area can be improved. Thermal conductivity and viscosity were found to increase in the nano fluids compared to base fluids when Estelle P et al.[20] tested the water-based carbon nanotubes physical and thermal properties. Another study by Mia M. et al. [21] evaluated the use of dry, minimal quantity, conventional lubrication during the machining of hardened steel. By measuring cutting force, the machining performance was investigated. When compared to the MQL application, a definite decrease in cutting force was seen. According to certain research, adding extreme pressure additives to vegetable-based lubricants had the unfavourable consequence of increasing surface roughness while at the same time generating a drop in cutting forces during the machining of AISI 304L steel. VBCFs may have the ability to replace hazardous cutting fluids based on petroleum in machining operations, it was finally mentioned. Due to the enhanced heat extraction capabilities of nanofluids, Srikant et al.'s [22] analysis of the usage of nanofluids with copper oxide additions in water-based fluids in machining operations showed a considerable decrease in tool tip temperature.

Recent developments in studies on the cooling and lubricating properties of nanofluids, as well as their potential use as cutting fluids in metal-cutting operations, were studied by Krajnik et al. [23]They concluded that in terms of tribological and thermal properties, properly manufactured appropriate nanofluids could outperform common cutting fluids. Nam et al. [24] conducted a number of micro-drilling tests using compressed air lubrication, pure minimal quantity lubrication with vegetable oil, and minimum quantity lubrication with nano diamond particles. The results showed that vegetable oil minimal quantity lubrication with nano diamond particles added performed better than pure vegetable oil minimum quantity lubrication. The optimal ratio of nanodiamond additives for reducing thrust force and drilling torque was 2.0 vol% for vegetable oil lubrication with minimum additions of nano diamond particles. In trials on (GnP)-enhanced vegetable oil minimum quantity lubrication in milling process, Park et al. [25]concluded that (GnP)-enhanced vegetable oil outperformed vegetable oil in terms of performance, likewise, 0.1 wt% of GnP was the ideal ratio for improving machining operations. According to Sharma et al., [26]research has used a variety of MQL advancements, such as nanofluid with MQL, to improve the machining properties of MQL, particularly for ultra hard materials. J. E. Manikanta et al. [27]studied the use of nanocutting fluid in the machining of the alloy SS304. They discovered that cutting speed, cutting fluid weight percentage, and depth of cut have the greatest effects on surface finish and MRR, respectively. Virdi et al. [28]tested the effectiveness of a nanofluid made from vegetable oil and Nikel-Cr alloy using MQL grinding. To make the nanofluids, 0.5 and 1 weight percent of nano CuO were combined with basic oils. The MQL approach and the polishing impacts of CuO nanoparticles at the cutting area were found to significantly improve surface finish and lower temperature. In order to machine titanium with the least amount of lubrication, Gaurav et al. [29]studied the performance of jojoba as a base oil and nano-mixed jojoba oil. Different nanoparticle concentrations (0.1, 0.5, and 0.9% by weight) were used to assess the performance of the nanofluid MQL. With the improved cooling and lubricating capabilities of nanofluid MQL, reductions of around 35–47% in surface roughness, tool wear, and cutting force were seen. For the purpose of environmentally friendly Inconel 800 machining, Gupta et al. [30]evaluated the efficacy of dry, vegetable oil-based MQL, graphene nanofluid combined with MQL (NMQL), and liquid nitrogen (N2) chilling. Liquid nitrogen and NMQL were reported to improve machining performance and lower overall energy consumption. Furthermore, the NMQL application resulted in a sizable decrease in tool wear (36.3%).

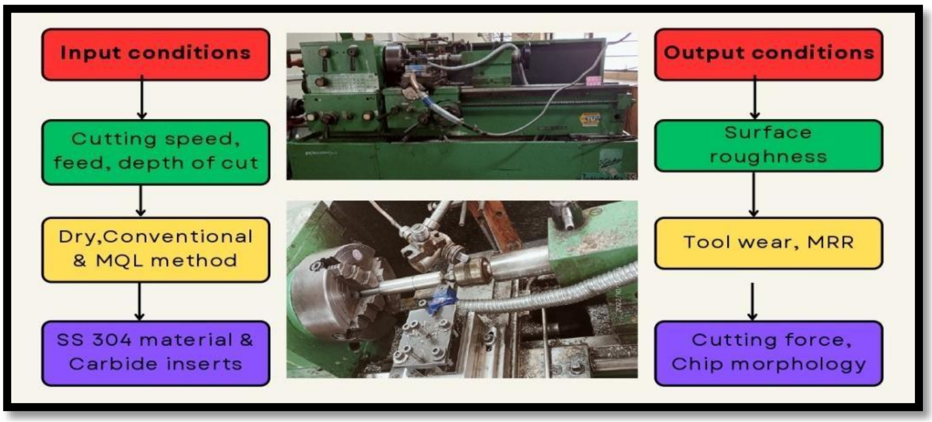

Fig 1. Methodology implemented for the work

According to findings in the literature, the current investigation is driven by the superior lubricating qualities of vegetable oil and nanoparticles. Utilising nanofluids in conjunction with MQL can improve machining performance by supplying superior lubrication and cooling at the cutting zone. Few studies, meanwhile, have been found that apply MQL to nanofluids that contain various nanoparticle weight percentages. Additionally, it has been discovered that nal_2o_3 produces lubricant films and can reduce heat generation by lowering friction during machining[31]. The objective of the work is to assess the machining reaction of CBGC oil added with varied concentrations of nal_2o_3 (0.4%, 0.8%, and 1.2%) by evaluating tool wear, chip morphology, cutting force, surface finish, and material removal rate.

2. Experimental Details

2.1 Workpiece and tool materials

SS 304 material with an average hardness of 201 BHN was used for the experimental research. The SS 304 has the following chemical composition: Fe is 69%, Cr 17.50–19.50%, Ni 8–10.50%, Mn 0.01-2.00%, C 0.01–0.07%, S 0.03%, and P 0.01–0.05%. The workpiece consisted of SS 304 cylindrical bars that were 50 mm in diameter and 200 mm long. There are significant applications for the workpiece material in the agricultural, automotive, and other industries. The experimental research involved the use of a coated carbide insert with ISO identifier SNMG 120408 NSU. Tool holder PSBNR2525 was used to hold tool inserts.

2.2. Preparation of nanofluid

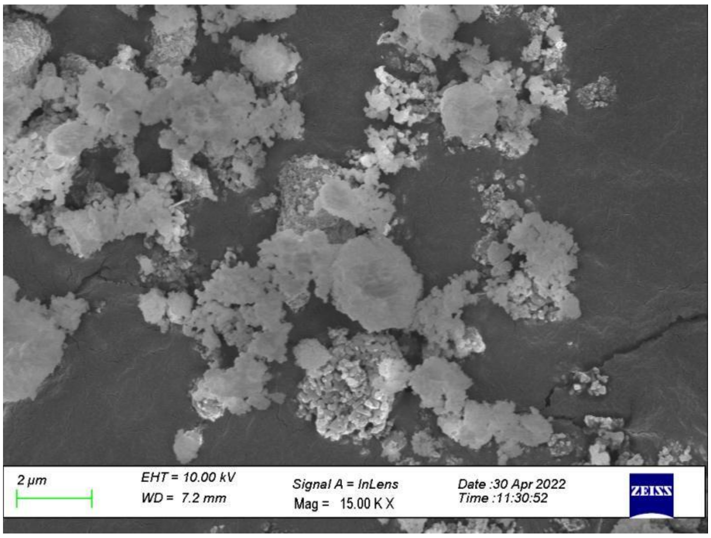

Fig 2: Scanning Electron Microscope image of al_2o_3

A base fluid called corn-based green cutting (CBGC) oil was used to combine nanopowder (nal_2o_3) with. Corn oil is prepared in previous study. Based on experimental results corn base green cutting oil selected with 10% Emulsifier content mixed oil[32]. Listed in Table 1 are the characteristics of CBGC oil. Al_2O_3 SEM picture is displayed in figure 2. The nanoparticle, which had a 99% purity rating and an average particle size of 40 nm, was employed. In order to create the nanofluid, nal_2o_3 was dispersed in base oil (CBGC oil) at various concentrations (0.4%, 0.8%, and 1.2% by weight). To achieve a consistent mixing of nal_2o_3 in CBGC oil, an ultra sonicator and magnetic stirrer were used. Additionally, to enhance the stability of the dispersion and lessen the clogging of nanoparticles in base oil, Sodium Do Dezyl Benzene Sulphate (SDBS) with 0.15% weight of nal_2o_3 was mixed.

2.2. Experimentation

As was said in the outset, using conventional cutting fluids raises environmental concerns and drives up manufacturing costs. In order to ascertain if solid lubricant and cutting fluid made from vegetables that are applied with MQL are efficient when used to machining stainless steel 304, research has been conducted. Based on the lathe machine characteristics and the workpiece material, respectively, cutting speed, feed, and depth of cut were selected for the experiment. These selected values were 150 m/min ,0.2 mm/rev and 0.5 mm. In addition, the MQL system, was utilised to supply lubricant under MQL (CBGC oil) and nMQL (CBGC oil+ nal_2o_3) environment.

The tests were conducted in dry, wet, MQL, and nMQL conditions (0.4%, 0.8%, and 1.2% concentration of nal_2o_3). The common cutting fluid, which was commercially available in the market, was used in the wet method at a flow rate of 1 L/min. A meager amount of cutting fluid was utilised in MQL, flowing at a rate of 300 mL/hr. As previously mentioned, nano-alumina (nal_2o_3) concentrations of 0.4%, 0.8%, and 1.2% in CBGC oil, with an average particle size of 40 nm, were used for the MQL machining.

Table 1. Thermo Physical properties of CBGC oil.

Oil	Viscosity (cP) @ 60^0C	Thermal conductivity (W/mK)	pH
Corn	32	0.15	8.92

According to the literature review, a nozzle with a diameter of 1 mm and angle of 30^o was chosen. A flow rate of 300 mL/hr of the lubricant mixture was applied while using compressed air at a pressure of 0.3 MPa. The experimental details are shown in Table 2.

Table 2. Experimental details.

Workpiece material	SS 304
Workpiece dimensions	Ø 30 × 200 mm length
Average hardness	201 BHN
Process parameters	speed (Vc)- 150m/min feed (f)- 0.2 mm/rev DOC- 0.5 mm
Tool holder	PSBNR2525 M12
Cutting tool	SNMG 120408 NSU
Lubrication strategy	
MQL	CBGC oil Flow rate- 300 mL/hr Air pressure- 4 bar
Wet	Conventional cutting fluid Flow rate- 1 L/hr
nMQL	CBGC oil + nal_2o_3 Flow rate- 300 mL/hr Air pressure- 4 bar Solid lubricant (%)-0.4,0.8,1.2 Solid lubricant particle size- 40 nm

Minimum cutting force, surface roughness, flank wear and maximum material removal rate were all taken into account when evaluating the efficacy of the lubricating conditions under discussion. To measure surface roughness, a surface roughness tester was employed[33]. Ra readings were taken along the edge of the workpiece three different times to decrease the variability. The maximum flank wear was considered instead of the average because the wear that was measured was so unequal. Through the use of an optical microscope, the growing tool wear has been seen. Cutting force is determined by means of a piezoelectric dynamometer (Kistler 9257B model).Calculating material removal rate involves using the weight difference between the workpiece before and after machining with respect to the machining time.

3. Results and Discussions

3.1 Surface roughness

A minimum value for surface roughness and the absence of any foreign particles on the surface are required for an outstanding surface finish to be generated. Because of this, it's crucial to keep the variables affecting the workpiece surface polish under control while it's being machined. The average surface roughness (Ra) of the machined workpiece is determined in order to evaluate the effectiveness of various cutting fluid conditions. Figure 3 shows a comparison of Ra values generated under various machining circumstances.

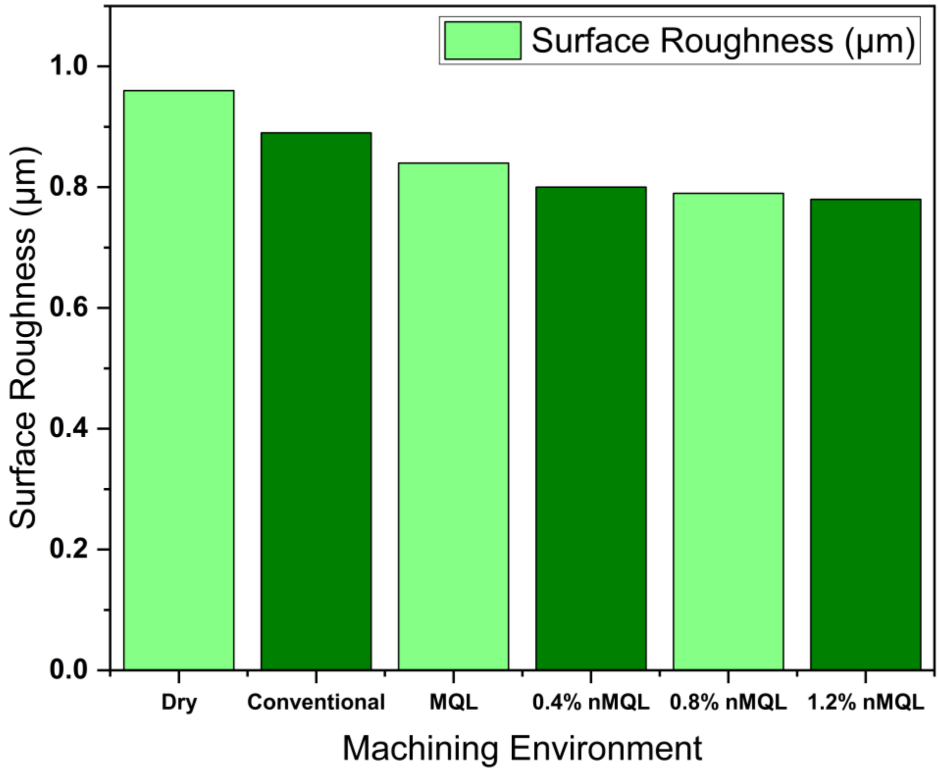

Fig 3. Analysing the surface roughness created by various machining environments

From the comparison, it is clear that applying nal$_2$o$_3$ to CBGC oil at concentrations of 0.4% and 0.8% resulted in the least amount of surface roughness. The highest surface roughness, however, has come from dry machining. The main mechanism is the ability of cutting fluid droplets to enter the cutting zone through compressed air, resulting in decreased temperature and friction. In order to maximise heat dissipation from the machining area and minimise tool wear and surface roughness, the nal$_2$o$_3$ demonstrates superior cooling and lubricating properties at a higher temperature Surface roughness (Ra) is decreased as a result of the interaction between MQL and nanofluids. Cryogenic and MQL applications with nano additives have been claimed to improve surface finishes. Additionally, the nanoparticles lower concentration and smaller particle size contribute to lessening friction in the machining area. The application of a high-pressure air-fluid mixture, which has led to easier chip removal and higher surface finish, is what makes nMQL with nal$_2$o$_3$ successful. Similar outcomes with increased machining performance were reported by Srikant et al. [19]using vegetable oil-based nano cutting fluids.

3.2 Tool Wear

Improved tool life is sought for sustainable machining and lowering tooling costs because tool consumption impacts the cost of machining [34].

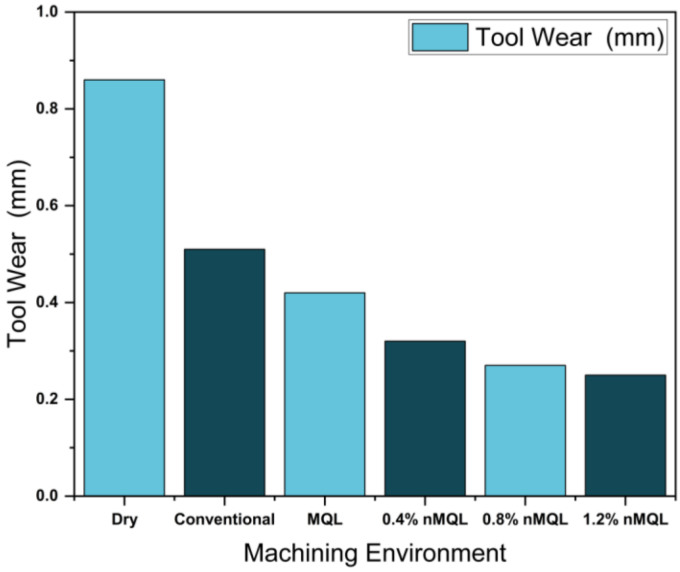

Fig 4. Comparison of the flank wear generated by various machining environments.

The machining zone's intense heat generation has an impact on the rate of tool wear and, consequently, tool life. The maximum flank wear (mm) recorded throughout the 3 min of cutting time in the examined machining conditions is shown in Figure 4. The maximum flank wear is seen during dry machining because to the lack of cooling/lubricating action and higher frictional heat. With the application of MQL and nMQL, lower flank wear is seen. Previous studies have shown that MQL is good in preserving a thin coat of lubricant, which lowers frictional heat generation during machining[35]. Previous studies came to the conclusion that using nanofluids improved tribological conditions and reduced friction and heat production[36]. As a result, it has helped the tool wear during nMQL application to decrease. In this study, nal_2o_3 at a concentration of 0.4% produced the least amount of flank wear when compared to dry and MQL conditions. The effectiveness of base oil and nanoparticle lubrication in reducing frictional effects in the machining zone, as well as the ability of the air-fluid mixture to penetrate into the cutting zone, are credited with the results[37]. Lower flank wear was the result of the CBGC oil's increased nanoparticle content, nevertheless. Cutting fluids' increased thermophysical characteristics are to blame for this[38].

3.3Material removal rate

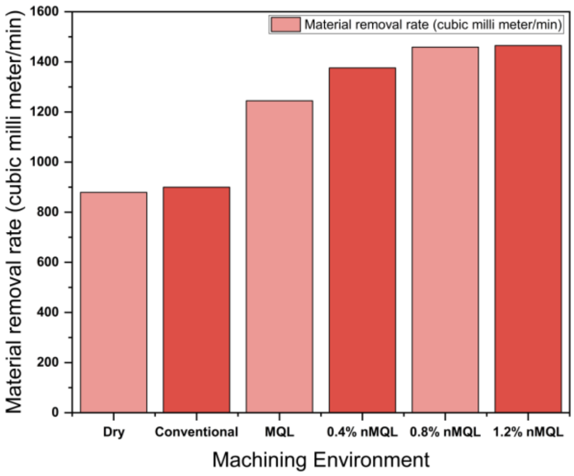

Fig 5. Rate of workpiece material removal in conditions of dryness, flooding, MQL, and nMQL.

In industries with greater production rates, material removal rate (MRR) is an important consideration. The largest factor affecting how much material is removed in a given amount of time is the cutting environment. Thus, the objective of this effort has been to investigate the effect of different lubricating conditions (dry, wet, MQL, and MQL with nal_2o_3) on the rate of material removal from the machined surface. Figure 5 compares the material removal rates attained in various machining settings. A little difference in the rate of material removal from the machined surface is observed with MQL and MQL with nal_2o_3 machining, illustrating the improved machining and resulting from nano alumina abrasion. As the concentration of nanoparticles in the cutting fluid rose, the rate of material removal increased linearly.

3.4 Cutting Force

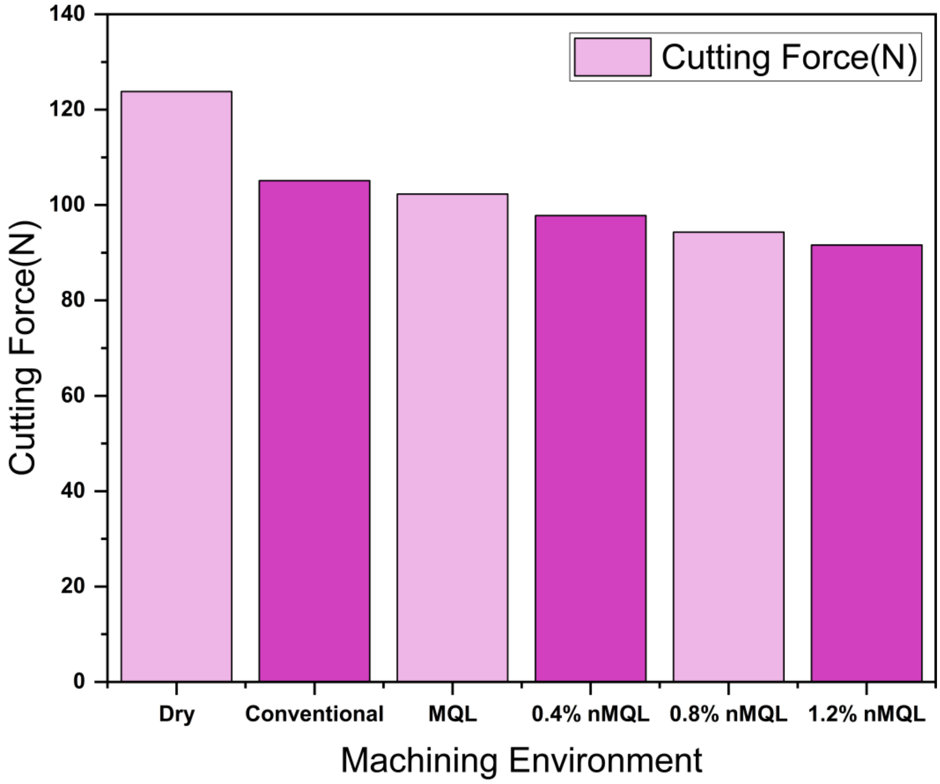

Fig 6. Comparison of the flank wear generated by various machining environments.

The cuttings force on SS304 when it is dry and when using vegetable fluids are shown in Fig. 6 over the course of the machining process. According to the results, Corn with 10% emulsifier beats conventional cutting fluid and other cutting fluid compositions, requiring less cutting force. The cutting forces barely changed when the cutting fluid's emulsifier level increased from 20% to 50%. Because stable emulsions only form at concentrations of 10% and any excess is suspended freely in the solution without impairing the cutting fluid's performance, the cause of this could be the absence of an emulsifier. The lack of an emulsifier could also be explained by the fact that a 10% emulsifier's viscosity might be on par with that of standard cutting fluids**.**

3.5 Chip Morphology

To evaluate the impact of the cooling/lubricating techniques, a chip morphology research is conducted. In order to avoid impediments and facilitate removal, a broken piece with a shorter length is preferred in machining. Figure 6 shows images taken with a camera of the chips produced under various milling conditions. Dry machining produces continuous chips because the material becomes softer as a result of the high temperature caused in the cutting zone. Segmented chips are made using MQL and MQL with nal_2o_3. This is explained by the development of a hydrodynamic lubricating layer between the tool rake face and the produced chips[39]. It is discovered that nMQL with nal_2o_3 has a significant impact on chip shape when compared to MQL and dry machining. The results are in line with the chip morphology that was shown while rotating AISI 4340 while employing al_2o_3 nanofluid[40].

Fig 6. Chip shapes produced during (a) dry (b) MQL [c) nMQSL machining are compared.

The continuous chips created during dry machining are difficult to remove from the machining zone, while the shorter lengths of the chips are easy to do so. The chips produced by nal_2o_3 are also thinner and have a smaller radius of curvature than those produced by other lubrication conditions. This can be understood by the fact that the concentration of nal_2o_3 was able to lower the temperature of the chips' surface. Overall, the experimental results demonstrated the effectiveness of vegetable oil-based nanofluid for Minimum Quantity Lubrication (MQL), greatly enhancing the machinability of stainless steel 304.

4. CONCLUSIONS

In the experiment that was given, it was examined how well CBGC oil worked when nal_2o_3 was applied in various amounts (0.4%, 0.8%, and 1.2%) during the machining of SS 304. The results achieved are contrasted with those of dry, wet, and MQL-assisted machining. Based on the findings, the following conclusions can be made.

1. With MQL application, the effectiveness of CBGC oil is seen in the improved lubricity. Additionally, the CBGC oil added with various amounts of nal_2o_3 (0.4%, 0.8%, and 1.2%) improved machining performance for the conditions taken into consideration.
2. Using corn oil and nal_2o_3 results in the anticipated improvement in the surface finish. A concentration of 0.4% of nal2o3 resulted in the least amount of surface roughness, but higher concentrations (0.8% and 1.2%) result in more severe surface roughness because of the lubricant mixture's higher viscosity and aggregated nanoparticles.
3. Corn oil and nal_2o_3 application showed a reduction in tool wear.
4. In comparison to dry, wet, and MQL applications, the greatest material removal rate is seen with the application of nMQSL.

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