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Research Article

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An Investigation on Influence of Novel Minimum Quantity Lubrication on Tool Flank Wear in Machining of Super Duplex Stainless Steel

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Abstract

The primary focus of this work is to study the effects of a novel minimum quantity lubrication (NMQL) or near-dry machining technique on tool flank wear of the tool inset in machining super duplex stainless steel (SDSS) and compare the surface finish with the machined surface performed by dry machining process. Two set of groups were taken for the study, i.e., control group (Dry machining) and the experimental group (Machining with minimum quantity lubrication (MQL) technique). The number of samples is calculated using the sample calculator. Twenty samples were taken for each group. In the control group, the machining operation is carried out on SDSS without any kind of lubrication. In the study group using a NMQL technique, the compressed lubricant is sprayed to the machining area. The tool flank wear of the inserts of each group is measured by microscopic images. The effect of the NMQL technique on the tool wear of the inserts is studied. The tool wear of the samples from NMQL is better than the samples obtained from the dry machining operation. It was concluded that there was a 60% of reduction in tool wear when the MQL technique is implemented over dry machining.

Keywords

Graphene nanoparticles, Tool wear, CNC machining, Dry machining, SPSS software, Sustainable production

Introduction

The crucial manufacturing process of machining, also referred to as "subtractive manufacturing," creates the required shape by removing undesirable components from raw materials. Making vehicle parts, mechanical parts, tools, dies, and molds are the principal uses for the machining process [1]. Green machining is the practice of applying environmentally friendly methods within the machining process to reduce its environmental impact. Some of the strategies to achieve green machining include the use of or near-dry machining, which drastically reduces the amount of coolant used during machining operation, thus lowering potential discharge of toxic waste. The selection of biodegradable coolants can also further decrease environmental impact. Another strategy is employing energy-efficient machine tools; these can decrease energy consumption and in turn, reduce carbon emissions. The integration of advanced materials and design techniques can decrease waste generation through an increase in tool life or more efficient use of material. Additionally, optimizing cutting conditions and parameters can achieve higher process efficiency, thus reducing energy usage and waste. Another approach is recycling or reusing machining waste, such as metal chips or used coolant, contributes to waste minimization. Through these approaches, the machining industry can move towards more sustainable and environmentally friendly practices, adopting the principles of green machining.

Cutting fluids, widely used in machining processes to reduce heat and friction between workpiece and tool, present several environmental and health challenges. Environmentally, the disposal of used cutting fluids can lead to soil and water contamination. These substances often contain non-biodegradable chemicals and heavy metals that can disrupt ecosystems and harm aquatic life. On the health front, prolonged exposure to cutting fluids has been associated with various health issues among workers. Direct contact can cause skin irritation, allergic reactions, or dermatitis. Even more concerning, the inhalation of mists or vapours generated from heated cutting fluids can lead to respiratory diseases, including occupational asthma and lung cancer. Furthermore, the handling and disposal of these fluids pose potential risks, due to their often flammable and chemically reactive nature. Therefore, it's of paramount importance to regulate and manage the use and disposal of cutting fluids to minimize these adverse effects. Measures such as the use of safer alternatives, personal protective equipment (PPE), and improved ventilation can mitigate some of these risks. Szczotkarz et al. [2] suggested that MQL can be used in manufacturing to achieve green manufacturing.

The total number of research papers published related to this work and sustainable production was 15200 in google scholar and 8045 in ScienceDirect in the past ten years. Siow et al. [3] analyzed tool flank wear of superalloy which is mainly used for high-temperature applications. Babu et al. [4] reported that tool flank wear is a key factor that directly affects the life of a cutting tool, making it an essential element to consider in machining operations. Flank wear occurs due to the abrasion between the tool's flank face and the finished surface of the workpiece [5]. Over time, this causes a wear land to form on the flank face, leading to deterioration of the tool and, eventually, tool failure. Increased flank wear not only shortens tool life but also compromises the quality of the machined product, potentially leading to substandard surface finish and dimensional inaccuracies in the machined part [2]. Flank wear is often used as a failure criterion in determining tool life, with a critical flank wear width often set as the point at which a tool is deemed to be 'failed'. It's crucial to monitor and control tool flank wear, as it directly influences both machining productivity and product quality [6]. Optimization of cutting parameters, application of proper tool coatings, use of enhanced cooling or lubricating techniques, and regular tool inspections can be employed to manage and minimize flank wear and extend tool life in machining operations. Dambatta et al. [7] studied the effect of MQL is a technique that can assist in reducing tool flank wear, thus, enhancing the tool life in machining processes. This method involves using a minimal amount of lubricant, precisely directed to the cutting interface which can significantly decrease the tool-workpiece interaction friction, and in turn, tool wear. The lubricant forms a boundary layer that minimizes metal-to-metal contact during the cutting process, reducing the heat generated, which is a major contributor to flank wear. By reducing heat with the lubricant, the thermal deformation of the cutting tool can also be minimized, thereby maintaining tool geometry and integrity Vasudevan, et al. [8] the lower volume of lubricant used in MQL reduces the likelihood of the lubricant influencing chemical wear, another significant aspect of tool wear. As such, application of MQL can reduce the rate of flank wear, prolonging tool life, and improving the efficiency of the machining process. This technique also aligns with the principles of green machining by considerably decreasing coolant consumption and waste.

According to the study's findings, very few studies on the effect of NMQL technique on tool wear of SDSS have been conducted. My motivation for conducting this research came from my experience and extensive theoretical knowledge of different machining procedures, MQL, tool wear measurement methodologies, sustainable production and metals and alloys and interest towards sustainable production. In this study, SDSS is being machined in various dry circumstances with minimal lubrication. It was an end-milling type of machining. This study's goal is to examine the effects of near dry machining technique technology on crater and tool flank wear.

Materials and Methods

This research work mainly consists of two groups namely control group and the study group. The CNC machining operation without any kind of lubrication is considered a control group. The machining operation using a NMQL technique i.e., the compressed lubricant is applied to the machining zone is considered a study group. To obtain better results, a few samples have been taken. The number of samples is calculated using a sample calculator. The number of samples taken for each group was 20 (N = 20) and the total number of samples was 40 (N = 40) [9].

For the control group, the machining operations are performed without lubrication. It is called dry machining. For this study SDSS is taken as a study material. SDSS represent a class of highly alloyed stainless steels that offer superior mechanical strength and corrosion resistance. These properties make them an attractive material choice for demanding applications particularly in the oil and gas, desalination, and chemical industries [10, 11]. The superior properties of SDSS are attributed to their dual-phase microstructure, comprising approximately equal proportions of austenite and ferrite. This balance of phases contributes to their superior strength, twice that of conventional austenitic and ferritic stainless steels, and improved resistance to diverse corrosion mechanisms, including pitting and stress corrosion cracking [12] Moreover, the enhanced resistance to chloride-induced corrosion makes SDSS ideal for applications in harsh saline environments. However, these superior properties often make SDSS challenging to machine, and they can exhibit poor machinability due to high strength and low thermal conductivity. Therefore, considerable attention is paid to developing optimal machining strategies to handle SDSS without significantly detracting from their desirable characteristics. The material was purchased at Viruvadia Traders, Chennai. The size of the specimen is 150 mm × 150 mm × 10 mm. The abovementioned coated carbide tools are used to machine the SDSS material. For the control group, the machining operations are performed without lubrication. It is called dry machining. The end milling operation was carried out and the feed rate and depth of cut was maintained. The CBN inserts are used to machine the SDSS for specified time limit and the tool wear is measured.

For the study group, the machining operations are carried out with NMQL technique set up figure 1 [13]. The set-up is shown in figure 2. Six slots were cut to measure the tool wear. The CNC machining operation has been performed using vertical machining centre EV 1020A which is shown in figure 3. Based on the literature survey, the machining parameters are selected The coated carbide tool insert was used to perform the CNC machining operation. The end milling operation was performed under dry operation conditions for the control group. The NMQL technique set-up is fitted, and the end milling operation was performed under NMQL technique for the study group for the same machining parameters.

After machining for the specified time, the tool inserts were collected and cleaned as shown in figure 4. The Metzer optical microscope is used to observe tool wear shown in figure 5. This is a portable optical instrument that allow accurately measure tool wear. The tool inserts was kept on the measuring platform. The microscopic images were captured. Then the images were exported to imageJ software. The tool wear is measured using imageJ software for the control group i.e., dry machining and study group i.e., MQL technique. The tool wear of all the samples are tabulated in table 1.

Results

Tool flank wear of the samples from the control group and study group were measured using tool wear testing machine SJ-410. The tool wear of both machined surfaces was further statistically analyzed using SPSS software and obtained values of various tests. The results are shown in table 2. The mean tool wear of the dry machining is 2.3160 and the mean tool wear for machined surface obtained in the MQL technique is 1.5610 with a standard deviation of 0.221 The bar graph is shown in figure 6. The X-axis denotes method of machining technique and Y-axis denotes the mean tool wear. This graph shows that the machined surface obtained in the MQL technique has a better surface finish with a significantly lower error deviation is shown in table 3.

Discussion

In this study, it was observed that tool wear has been reduced while MQL technique has been implemented when compared with dry machining i.e., without any coolant while machining the monel material. MQL also plays a pivotal role in dissipating heat generated during machining. By minimizing the heat buildup at the cutting edge, MQL helps prevent thermal softening and premature wear of the tool material, particularly in high-speed cutting operations. In addition, proper chip evacuation is crucial to reducing flank wear. MQL assists in the efficient removal of chips from the cutting zone, preventing their accumulation on the tool's flank surfaces, which can lead to accelerated wear. The near dry machining technique reduces the wear between the tool and workpiece which leads to reduction in the tool wear. The tool wear has been measured with a metzer microscope. The combined effects of reduced friction, effective heat management, and improved chip evacuation contribute to prolonged tool life when MQL is employed. Tools subjected to MQL tend to exhibit slower rates of flank wear, ultimately leading to fewer tool changes and increased machining efficiency.

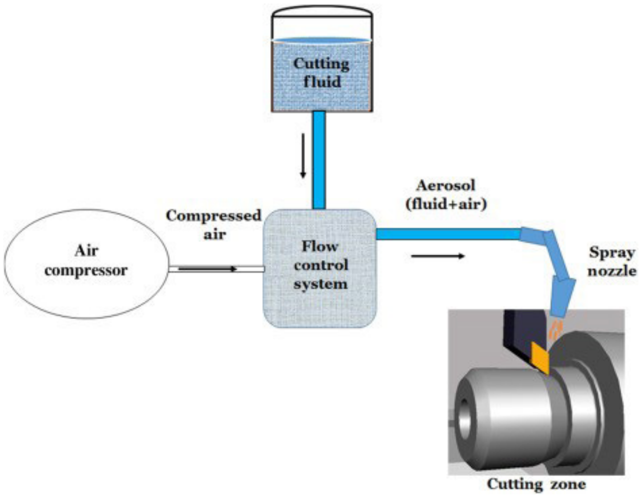

Figure 1: MQL set-up line diagram.

Figure 2: MQL set-up.

Figure 3: Vertical milling machine YCM XV1020A.

The obtained results were compared to other research projects of a similar nature. Sujith and Mulik [14] focused on the milling of the SDSS alloy was tested with the MQL approach using cutting fluids with graphene-dispersed vegetable oil bases. By incorporating graphene nanoparticles into the cutting fluids made of vegetable oil, they were created. It has been shown to prolong tool life and reduce tool wear. It was observed minimal flank wear and crater wear. Kuntoğlu et al.

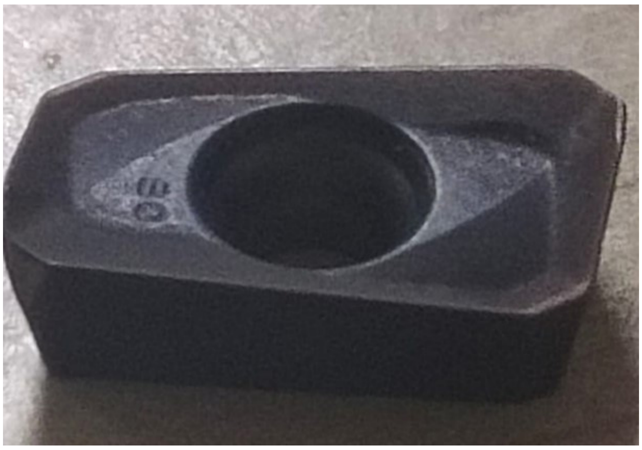

Figure 4: Flank wear of the tool insert.

Figure 5: Metzer microscope.

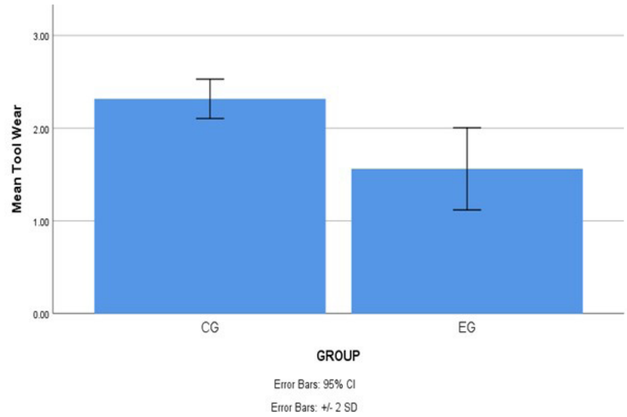

Figure 6: Mean tool wear comparison of machined surface from dry machining and MQL technique using bar graphs. SR for machined surface from dry machining is 2.3160 with a standard deviation of 0.10615 and the SR for machined surface obtained in the MQL technique is1.5610 with a standard deviation of 0.22152. X-axis denotes method of machining technique and Y-axis denotes the mean tool wear. This graph shows that the machined surface obtained in the MQL technique has a better surface finish with a significant lower error deviation.

[15] investigated tool flank wear analysis for MQL assisted milling of steel material. Because of its special material qualities, structural steel can be used in significant technical applications like heavy machinery and ships. In the field, tool flank wear (VB), which indicates remaining tool life and is practical and simple to measure, is highly recommended. Cutting speed, feed rate and depth of cut were included in the experimental plan and Taguchi L9 design was adopted. Deivanathan et al. [16] and Kumar et al. [17] commented that MQL presents an effective strategy for minimizing flank wear, leading to extended tool life in machining operations. This process involves the delivery of a minute, accurate quantity of lubricant directly to the tool-workpiece interaction zone.

The factors affecting this study are wt.% ratio of the nanoparticles, viscosity of the vegetable oil, compressor pressure and nozzle diameter [18]. As the machining operation is performed in the advanced vertical machining center, there is limitation to mention. In future, there is a possibility to study the effect of different nanoparticles, different vegetable oil and mineral oil. The same study can be conducted for different volume fractions of nanoparticles and varying particle sizes. MQL is an environmentally friendly lubrication technique, as it uses minimal quantities of lubricant compared to conventional flood cooling methods. This not only reduces the cost associated with coolant usage but also minimizes waste and environmental impact. The lubricant serves to create a boundary layer that reduces metal-to-metal contact and, consequently, the frictional heat generated during the cutting process. This reduction in heat loosens its contribution to the tool's flank wear. Further, by limiting thermal deformation of the tool, the lubricant helps maintain its geometry and integrity. Lower lubricant volume in MQL also curbs the chance of the lubricant triggering chemical wear, another significant aspect of tool wear. Hence, the application of MQL can reduce flank wear rates, prolong tool life, and improve the overall

Table 1: Tool wear in of tool inserts from dry machining and MQL technique.

Sample no.	Tool wear dry machining (mm)	Sample no.	Tool wear dry machining (mm)	Sample no.	Tool wear MQL technique (mm)	Sample no.	Tool wear MQL technique (mm)
1	2.33	11	2.46	1	1.81	11	1.56
2	2.39	12	2.4	2	1.66	12	1.57
3	2.42	13	2.45	3	1.34	13	1.24
4	2.44	14	2.19	4	1.46	14	1.82
5	2.34	15	2.25	5	1.58	15	1.94
6	2.45	16	2.18	6	1.82	16	1.14
7	2.18	17	2.22	7	1.83	17	1.38
8	2.14	18	2.21	8	1.74	18	1.4
9	2.24	19	2.37	9	1.68	19	1.37
10	2.34	20	2.32	10	1.44	20	1.44

Table 2: Descriptive table representing mean and standard deviation of tool wear of dry machining with MQL set-up.

Group statistics					
		N	Mean	Std. deviation	Std. error mean
Flank tool wear	Control group	20	2.3160	0.10615	0.02374
	Study group	20	1.5610	0.22152	0.04953

machining efficiency. Additionally, the approach aligns with sustainable machining practices, as it significantly lowers coolant consumption and waste.

Conclusion

In conclusion, MQL undeniably stands out as a best-practice technique for promoting green machining in modern manufacturing. Its ability to significantly reduce the consumption of lubricants, minimize waste, and lessen the environmental footprint associated with machining processes is remarkable. MQL's capacity to extend tool life, reduce tool wear, and enhance machining efficiency not only leads to substantial cost savings but also aligns with the imperative of sustainable manufacturing practices. By providing an effective solution for the reduction of both operational costs and environmental impact, MQL demonstrates its potential to revolutionize the machining industry. As industries increasingly prioritize sustainability and environmental responsibility, MQL emerges as a pivotal choice, demonstrating that it is not only beneficial for productivity but also for our planet's well-being. Within the limits of study, there is a 60% of reduction in tool wear when the near dry machining technique is implemented over dry machining. In conclusion, near dry

Table 3: Levene's test for equality and t-test for equality of means.

Independent samples test									
Roughness	Levene's test for equality of variances		T-test for equality of means						
	F	Sig.	t	df	Significance	Mean difference	Std. error difference	95% confidence interval of the difference	
					2-failed			Lower	Upper
Equal variances assumed	10.739	0.0021	13.745	38	< 0.001	0.002	0.05493	0.64381	0.86619
Equal variances not assumed	-	-	13.745	26.288	< 0.001	0.002	0.05493	0.64235	0.86765

machining is a promising method that has the potential to improve machining efficiency, reduce costs, and minimize environmental impacts in the metalworking industry. While there are still some limitations and challenges associated with MQL, ongoing research and development in this area are likely to lead to further improvements in the performance and applicability of this technology. The NMQL technique helps us to achieve sustainable production.

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None.

Conflict of Interest

None.

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