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Influence of Novel Minimum Quantity Lubrication Technique on Surface Roughness of Super Duplex Stainless Steel in Comparison with Dry Machining

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Abstract

Aim: The objective of this work is to compare the surface roughness (SR) of machined component of super duplex stainless steel (SDSS) using a novel minimum quantity lubrication (NMQL) technique and compare the SR of the machined component by dry machining process.

Materials and Methods: Two set of groups were selected for the study i.e., the control group and the study group. The number of samples is calculated using the sample calculator. Twenty pieces are taken for each group. In the control group, the machining operations were carried out on SDSS without lubrication i.e., dry machining. In the study group, a NMQL technique is implemented where the compressed lubricant is applied to the machining zone. The SR of each group is measured by a SR tester. The effect of the NMQL technique on SR is studied. The SPSS software is used for statistical analysis. The number of the samples was calculated by keeping the alpha value 0.05 and G-power as 80%.

Results: The SR of MQL is lesser than the samples obtained from the dry machining operation. The significant value obtained is p = 0.001, which is less than 0.05. Therefore, there is a statistically significant difference between the groups.

Conclusion: Within the limits of study, There is a 63% of improvement in the surface finish when the MQL technique is implemented over dry machining.

Keywords

Novel minimum quantity lubrication technique, Graphene nanoparticles, Surface roughness, CNC machining, Dry machining, SPSS software, Sustainable production

Introduction

Sustainable production is the process of manufacturing products in a manner that minimizes negative impacts on the environment while also meeting the needs of present and future generations. It involves using resources efficiently, reducing waste and pollution, and promoting social responsibility. Machining with minimum quantity lubrication (MQL) system has been one of the sustainable production techniques that has received a lot of attention over the years. The cost of modern machining techniques and the demand for high-quality standards are constantly under pressure. For more than ten years, MQL has been recommended as a remedy for the problems. MQL offers several advantages over dry machining approaches. By significantly reducing the use of cutting fluid compared to traditional cooling methods, MQL is not only cost-effective but also environmentally responsible. The salient feature of MQL is that it minimizes the quantity of coolant used, which substantially lessens the cleanup requirements and reduces machine downtime, contributing to increased productivity.

Moreover, MQL is known to generate less aerosol mist, bolstering the safety and air quality in the work environment. Fascinatingly, certain studies suggest that MQL can extend the service life of tools as it directs the lubricant to the cutting edge, providing optimum cooling where most imperative. Complementing these benefits is the fact that MQL produces less waste, mitigating both the impacts and costs associated with coolant waste disposal. The added benefit of ease of integration with existing machinery sustains its practicality in various operational setups [1]. In his research work, investigated MQL could potentially produce better surface finishes on machined parts by attenuating the severe temperature fluctuations experienced during dry machining. In conclusion, while MQL may not be suitable for every machining operation, it certainly presents potential enhancements in terms of cost, environmental impact, productivity, and quality of output. This study focuses on analysing the stress corrosion cracking (SCC) and machinability behaviours of SDSS [2]. This study examines the use of vegetable oil during the machining of SDSS using the MQL system. MQL uses significantly less cutting fluid than flood cooling, making it a more cost-effective and environmental-friendly option [3]. SDSS presents significant challenges when it comes to machining due to its unique material properties. Characterized by a dual-phase microstructure of equal proportions of austenite and ferrite, SDSS possesses a high toughness and strength, leading to an increased tool wear rate during machining. This is further compounded by the material's poor thermal conductivity, which results in excessive heat concentration in the machining zone. The built-up heat may not only accelerate tool wear, but also cause thermal distortion of the workpiece, reducing its dimensional accuracy and the quality of its surface finish [4]. SDSS is prone to work hardening, further increasing the difficulty of machining as the cutting process itself can increase the hardness of the material. Taken together, these qualities necessitate careful selection and monitoring of machining parameters, advanced tool materials, and possibly the use of effective cooling strategies to efficiently machine SDSS.

The total number of research papers published related to this work and sustainable production was 8,000 in Google Scholar and 1800 in ScienceDirect in the past ten years [4]. The intension of this work was to perform an experimental assessment of the impact of machining techniques on SR during end milling of aluminum 6061 under near-dry machining conditions [5, 6]. In metal machining operations, the MQL main purpose is to act as a coolant and lubricant to reduce friction and tool wear. In accordance with this model, the feed rate, spindle speed, and the percentage of SiC in the surface weight were the three variables that had the greatest influence on SR. Through testing, it was established that the system can estimate SR (Ra) in a MQL setting with an accuracy of roughly 89.5%. conducted an experiment on MQL on tool wear and SR in CNC turning [7]. Due to the high hardness of bearing steel materials like AISI 52100 steel, which results in low productivity and high manufacturing costs, machining AISI 52100 steel was subjected to an experimental investigation using the Taguchi analysis in the current work. Cutting parameters were taken into consideration, and their direct and interaction effects on turning performance in terms of tool flank wear and SR were investigated under MQL cooling conditions of these materials is one of the more difficult domains in the metal cutting industries [8]. T points out the susceptibility of SDSS to work hardening. The cutting process can inadvertently intensify material hardness, thereby amplifying the machining difficulty. The best parameter values have been discovered for turning AISI 304 with a coconut oil-based MWF under MQL conditions. Out of the above work [4] is the best study related to this work.

The research found that there have been very few investigations on the influence of MQL of SR on the SDSS. The motivation for conducting this research is obtained from my experience and extensive theoretical knowledge of several machining operations, including MQL, SR measurement techniques, and metals and alloys and interest towards the sustainable production. The intension of this study is to compare the SR of SDSS to the SR of dry machining using a novel near-dry machining approach.

Materials and Methods

This research work mainly consists of two set of groups namely control group and the study group. The 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. 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].

DSS exhibits greater toughness and weldability. They're made to offer greater corrosion resistance, especially against chloride stress corrosion and chloride pitting corrosion. The material has been procured from Virwadia Metals Alloys, Chennai. The specimen size is 150 mm × 150 mm × 10 mm. The coated carbide tools are used to machine the duplex stainless-steel material. The machining settings are maintained based on the literature review. The feed rate is 10 mm per minute, the depth of cut is maintained at 0.2 mm, and the spindle speed is 1200 rpm. For the control group, the machining processes are completed without the lubrication group, the machining processes are completed without lubrication. It is known as "Dry machining". Twenty slots were cut to measure the SR.

For the study group, the machining operations are carried out with MQL set up as shown in figure 1 [10]. A clean manufacturing method known as "near-dry machining". For most machining processes, flow rates between 10 and 100 ml/h are frequently used. The set-up is shown in figure 2. The pressurize coolant i.e., vegetable oil mixed with small quantity of graphene nanoparticles is supplied at the cutting zone. Six slots were cut to measure the SR and table 1 contains all SR data. The vertical machining center EV 1020A, which is seen in figure 3, was used to carry out the CNC machining operation. The machining settings are maintained based on the literature review. The feed rate is 10 mm per min, the depth of cut is maintained at 0.2 mm, and the spindle speed is 1200

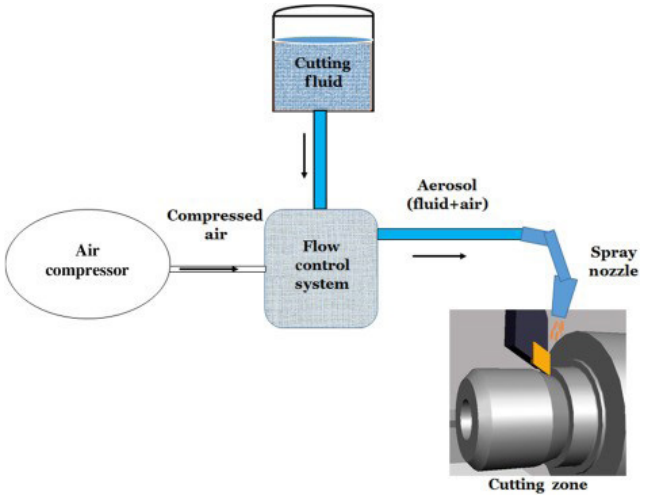


Figure 1: MQL set-up line diagram.



Figure 2: MQL set-up.

rpm. The CNC machining process was carried out using the coated carbide tool insert. For the control group, the end milling procedure was carried out in a dry operating environment.



Figure 3: Vertical milling machine YCM XV1020A.

For the study group, the end milling operation was carried out using the MQL technique while the MQL setup was installed.

After performing CNC machining operations, the specimens were cleaned as shown in figure 4. In the testing procedure the surface irregularities was found out. The SR is measured using SR measuring instrument Surf test SJ-410 which is shown in figure 5. This portable measurement device that accurately measure the roughness. The test specimens are placed on the cast iron platform of measuring instrument. The probe moves over the surface of the test specimen for a distance of 10 mm and measure the SR. The SR of the twenty samples from control group (dry machining) and study group (which uses the MQL approach) were measured. The SR value Ra is measured. The Ra values are tabulated in table 1.

Table 1: Obtained SR values (Ra) of machined surface from dry machining and MQL technique.

Sample no.	SR dry machining (Ra)	Sample no.	SR dry machining (Ra)	Sample no.	SR MQL technique (Ra)	Sample no.	SR MQL technique (Ra)
1	1.267	11	0.936	1	0.625	11	0.450
2	1.263	12	0.915	2	0.576	12	0.429
3	1.255	13	0.996	3	0.537	13	0.402
4	1.245	14	0.855	4	0.534	14	0.374
5	1.233	15	1.227	5	0.525	15	0.348
6	1.222	16	1.450	6	0.517	16	0.326
7	1.205	17	1.350	7	0.503	17	0.289
8	1.111	18	1.198	8	0.489	18	0.265
9	1.104	19	1.200	9	0.472	19	0.255
10	0.955	20	1.230	10	0.463	20	0.243



Figure 4: SDSS after machining.



Figure 5: Surface roughness tester SJ-410.

SR is the dependent variable, and the independent factors are cutting speed, feed rate, depth of cut, graphene nanoparticles size, percentage of graphene nanoparticles and castor oil. The significance for each of the 20 samples from the study group and control group is determined using the SPSS software. SR versus trial number graphs were used for the analysis on two set of groups of work pieces and the table contains SR.

Results

The SR of the samples from the control group and study group were measured using SR testing machine SJ-410. The SR 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 SR of the dry machining is 1.1609 with a standard deviation of 0.15556 and the mean SR for machined surface obtained in the MQL technique is 0.03772 with a standard deviation of 0.03772. The bar graph is shown in figure 6. The X - axis denotes method of machining technique and Y - axis denotes the mean SR. This graph shows that the machined surface obtained in the MQL technique has a better surface finish with a significantly lower error deviation. The significant value obtained is p = 0.001, which is less than 0.05. Therefore, there is a statistically significant difference between the groups.

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

Group statistics					
	Group	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Roughness	CG	20	1.1609	0.15556	0.03479
	EG	20	0.4268	0.11427	0.02622

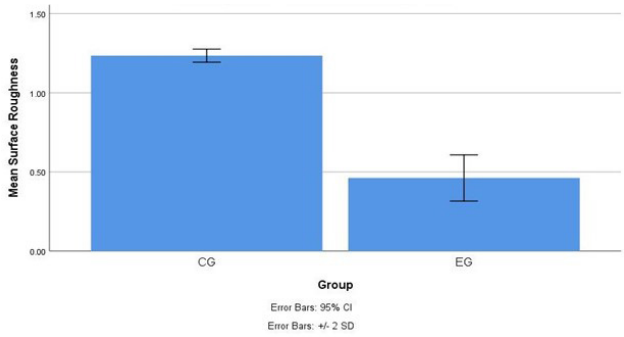


Figure 6: Mean SR comparison of machined surface from dry machining and MQL technique using bar graphs. SR for machined surface from dry machining is 1.1358 with a standard deviation of 0.19518 and the SR for machined surface obtained in the MQL technique is 0.4133 with a standard deviation of 0.04143. X - axis denotes method of machining technique and Y - axis denotes the mean SR. This graph shows that the machined surface obtained in the MQL technique has a better surface finish with a significant lower error deviation.

The results revealed that near-dry machining has a better surface finish than dry machining. Dry machining has a 1.1609 mean SR. Surface finish has improved because the mean SR of MQL machining is 0.4133. Table 3 shows the t-test for equality of means in independent samples, as well as Levene's test for equality.

Discussion

In this study, we observed that SR has been reduced while MQL technique has been implemented when compared with dry machining i.e., without any coolant while machining the SDSS material. The near-dry machining technique reduces the friction between the tool and workpiece which leads to improvement in surface finish.

The results were compared with similar research works. In one previous work, the MQL technique with castor oil was experimented on in the milling of stainless steel [11]. The study by [12] the author compared the performance of MQL using vegetable oil and synthetic oil. The study found that vegetable oil had a lower cutting force and temperature than synthetic oil, indicating that it may be a more effective lubricant for MQL. In another work by [13] the performance of MQL using different nozzle designs, including a straight nozzle, an inclined nozzle, and a spiral nozzle. The study found that the spiral nozzle produced the best machining performance, with lower cutting forces and better surface finishes. The media used in MQL operations is typically plain oil, but certain applications have also used an emulsion or water. The media most frequently employed in near-dry machining applications

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	
					One-sided p	Two-sided p			Lower	Upper
Equal variances assumed	1.552	0.0221	16.719	37	0.000	< 0.001	0.73401	0.04390	0.64505	0.82296
Equal variances not assumed	-	-	16.851	34.846	0.000	< 0.001	0.73401	0.04356	0.64557	0.82245

are fatty alcohols and synthetic esters. The medium chosen will depend on the supply type, the material being used. It was proved that it improved the milling characteristics of the stainless steel. Singh et al. [14] compared various technologies such as cryogenic cooling, little lubrication, and conventional cooling they had selected for MQL. They had selected AISI 304 steel as work material for shaping the tools. When compared to flood lubrication, MQL significantly reduced tool wear by 70%. This happens as oil penetrates further into the machining zone and provides adequate lubrication. The outcomes demonstrated the MQL approach, which uses lubricant and nanoparticles to reduce cutting temperatures and enhance SR [15]. The tiny amount of lubricant can effectively form a thin layer between the cutting tool and the workpiece, reducing friction and thus minimizing heat generation. As heat is a primary cause of tool wear and can affect surface integrity, a reduction in heat protects the tool's cutting edges, leading to a better surface finish. According to [16, 17], he concluded that MQL method decreases the chance of chip adhesion to the tool's surface, effectively preventing built-up edge formation that may compromise surface finish. Thus, the use of MQL in machining operations can result in an improved surface finish through a reduction in friction, heat production, tool wear, and chip adhesion.

The percentage weight ratio of the nanoparticles, the vegetable oil's viscosity, compressor pressure, and nozzle diameter are the variables affecting this study. Because the machining operation is performed in a sophisticated vertical machining center, there is one limitation to be aware of. Future research may examine the effects of various nanoparticles, vegetable oils, and mineral oils. The same research can be done with nanoparticles of various sizes and volume fractions.

Conclusion

Within the parameters of the investigation, the impact of a unique near-dry machining approach on SR during the machining of SDSS has been investigated. The SR of the innovative MQL machining process was compared to that of the dry machining method. This is because of MQL 's capacity to divide the oil particles into smaller parts. As a result, as compared to flood lubrication, these particles have a ball bearing effect that helps minimize roughness values. There is 63% of improvement in the surface finish when the MQL technique has been implemented over dry machining. In conclusion, MQL is a promising technology that has the potential to improve machining efficiency, reduce costs, and minimize environmental impacts in the metalworking industry. The MQL technique is a promising technique for sustainable production. Ongoing research and development in this area are likely to lead to further improvements in the performance and applicability of this technology which leads to sustainable production.

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None.

Conflict of Interest

None.

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