Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-193

Research Article

Open Access

Examine the Influence of Novel Cryogenic Machining on Tool wear in Milling of Super Duplex Stainless Steel Alloy

Mandala Ajay Naidu and B Navin Kumar*

Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

***Correspondence to:**
B Navin Kumar
Department of Mechanical Engineering,
Saveetha School of Engineering,
Saveetha Institute of Medical and
Technical Sciences,
Saveetha University,
Chennai, Tamil Nadu, India.
E-mail: navinkumarb.sse@saveetha.com

Received: July 31, 2023
Accepted: November 01, 2023
Published: November 03, 2023

Citation: Naidu MA, Kumar BN. 2023. Examine the Influence of Novel Cryogenic Machining on Tool wear in Milling of Super Duplex Stainless Steel Alloy. *Nano World J* 9(S3): S1093-S1098.

Published by United Scientific Group

Abstract

The primary focus of this work is to study the impact of a novel cryogenic machining technique of tool flank wear in machining of super duplex stainless steel (SDSS) and compare the surface finish of the samples 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 study group (Machining with cryogenic machining 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 novel cryogenic machining technique, the compressed lubricant is sprayed to the machining area. The flank wear of the cutting tool of each group is measured by microscopic images. The influence of the novel cryogenic machining technique on the tool wear of the inserts is studied. The number of the samples was calculated by keeping the alpha value 0.05 and G-power as 80%. The flank wear of the cutting tool of the samples from novel cryogenic machining is lesser than the samples obtained from the dry machining operation. It was noticed that there is a 65% reduction in tool wear when the cryogenic machining technique has been implemented over dry machining.

Keywords

Novel cryogenic machining, Co_2 gas, Tool wear, Milling, Super duplex stainless steel Sustainable production

Introduction

Machining is an essential process in the manufacturing industry, used to create a wide range of products with high precision and accuracy. With advancements in technology and materials, machining is becoming more efficient and effective, allowing manufacturers to produce higher-quality products at a lower cost [1]. Green machining holds paramount importance in today's manufacturing landscape, as it represents a conscientious shift towards sustainable and environmentally responsible practices. In an era where environmental concerns and resource conservation have taken center stage, adopting green machining techniques is not only a moral obligation but also a practical necessity [2]. One of the primary goals of green machining is to reduce the use of cutting fluids, which are often used to cool and lubricate the machining process. Traditional cutting fluids can contain harmful chemicals and pollutants that can be harmful to both human health and the environment. Therefore, green machining employs alternative cutting fluids such as cryogenic machining. By reducing energy consumption, minimizing waste generation, and employing eco-friendly lubrication methods like minimum quantity lubrication (MQL), green machining significantly reduces the environmental footprint of manufacturing operations. Moreover, it leads to substantial cost savings through improved efficiency and reduced resource consumption. Beyond these economic and ecological benefits, green machining aligns with the global commitment to combat climate change and preserve our planet's resources for future generations. Embracing green machining is, therefore, a pivotal step towards ensuring a sustainable and responsible future for the manufacturing industry and the world [3, 4]. Another significant benefit of cryogenic machining is the reduction in heat generation during the machining process. The heat generation can be a significant problem in traditional machining operations, leading to thermal distortion of the workpiece, reduced cutting tool life, and poor surface finish [5]. By using cryogenic fluids to cool the workpiece and cutting tool, the amount of heat generated during machining can be significantly reduced, resulting in improved surface finish, dimensional accuracy, and overall part quality [6]. The current work is to minimize the tool wear of the tool insert while machining SDSS using a novel cryogenic machining and compare it with surface roughness of the dry machining process. Szczotkarz et al. [7] suggested that cryogenic machining can be used to achieve sustainable manufacturing.

The total number of research papers published related to this work and sustainable production was 17697 in google scholar and 5465 in ScienceDirect in the past ten years [8]. The author analyzed that the machining community is becoming more interested in the technique of cryogenic machining because of the rise in demand for ecologically friendly manufacturing methods. The role of cryogenic machining in achieving green manufacturing cannot be understated. Cryogenic machining employs the use of extremely low temperatures to cool and lubricate cutting tools during machining processes, and this innovation contributes significantly to the green manufacturing paradigm. By reducing or even eliminating the need for conventional coolants and lubricants, which are often associated with environmental hazards and waste, cryogenic machining promotes a more sustainable and eco-friendly approach to manufacturing. This technique not only curtails the consumption of resources but also enhances tool life, reduces energy consumption, and minimizes waste generation [9]. Additionally, the use of cryogenic fluids like liquid nitrogen ensures a clean and non-toxic working environment, aligning perfectly with the broader goal of environmentally responsible production [10]. Dambatta et al. [11] studied the effect of cryogenic machining emerges as a key enabler of green manufacturing, allowing industries to uphold their commitment to sustainability while simultaneously improving machining efficiency and product quality. It was considered that research work is closely related to this research work.

The researchers are focusing on manufacturing parts and components using sustainable and eco-friendly methods. It involves reducing the environmental impact of manufacturing processes while still producing high-quality products. According to the findings of the research, only a few studies have been conducted on sustainable production and effects of cryogenic machining on tool wear of the SDSS. The effect of cryogen on work material, the effect of rate flow, the effect of cryogen on ferrous and nonferrous materials have not studied thoroughly. The experimental and depth theoretical knowledge about various machining operations, cryogenic machining technique, tool wear measurement techniques, metals and alloys motivated me to carry out this research work. This study is related to the machining of SDSS under different dry conditions and cryogenic machining. The machining type was ending milling. The aim of this study is to analyze the influence of cryogenic machining technique which is one of the sustainable production techniques on flank wear and crater wear.

Materials and Methods

This research work mainly consists of two set of sample 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 novel cryogenic machining 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. Sample size calculation is a crucial step in the design of experiments as it significantly impacts the validity and reliability of the results derived. Essentially, the calculation of an appropriate sample size is a balance between statistical power and practical feasibility. Statistical power refers to the probability that the experiment will detect an effect of a certain size, should it exist [12]. Having a larger sample size increases statistical power, thereby limiting the probability of type II errors (false negatives). However, there is a practical limit to sample size, often imposed by factors such as resource availability and time constraints. Therefore, methodologies such as power analysis, which considering the desired confidence level, expected effect size, and the acceptable error margin, are typically used in determining an optimal sample size. It's important to note that an insufficiently small sample can lead to unreliable results, while an unnecessarily large sample can boundlessly consume resources and time. Thus, careful consideration must be given to sample size calculation to ensure both effective and efficient experimentation. The number of samples taken for each group was 20 ($n = 20$) and the total number of samples was 40 ($n = 40$) [13].

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. 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 control group, the machining operations are carried out without coolant which is termed as dry machining. The workpiece has been fitted in the machine vice. The CBN inserts were fitted in the tool holder. The program has been written for cutting the slots. The speed of the spindle, feed rate are chosen from the standard literature [14]. The program has been executed. The required slots were obtained by dry machining.

For the study group, the machining operations are carried out with cryogenic machining set up [15]. Cryogenic machining is a manufacturing process that involves cooling the cutting tool and workpiece to very low temperatures using Co_2 gas or other cryogenic fluids. This technique can improve machining performance by reducing tool wear, increasing material removal rates, and improving surface finish. The process can also reduce the formation of thermal damage to the workpiece and the generation of harmful particles. The set-up is shown in figure 1. The set-up is shown in figure 2. Six slots were cut to measure the flank wear of the tool insert. 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 taken, 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 cryogenic machining set-up is fitted and Co_2 gas is supplied to the cutting zone the end milling operation was performed under cryogenic machining 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 was measured for the dry machining samples and cryogenic machining samples. The tool wear samples are tabulated in table 1.

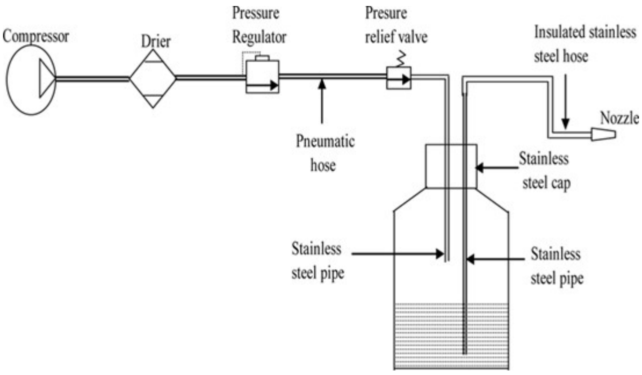

Figure 1: Cryogenic machining set-up line diagram.

Figure 2: Cryogenic machining setup.

Figure 3: Vertical milling machine YCM XV1020A.

Results

Tool flank wear of the tool insert of the samples from the control group and study group were measured using Metzer microscope. The flank wear of the tool insert 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 flank wear of the tool insert of the dry machining is 2.374 with a standard deviation of 0.0848 and the mean flank wear of the tool insert for the machined surface obtained in the cryogenic machining technique is 1.5275 with a standard deviation of 0.2199. The bar graph is shown in figure 6. The X axis denotes method of machining technique and Y axis denotes the mean flank wear of the tool insert. This graph shows that the machined surface obtained in the cryogenic machining technique has a better Surface finish with a significantly lower error deviation.

The results prove that surface finish has been improved in the cryogenic machining compared to dry machining. The mean flank wear of the tool insert of dry machining is 1.1358. The mean flank wear of the tool insert of cryogenic machining is 2.374 which is evident that surface finish has improved. The table 3 shows the levene's test for equality and t-test for equality of means independent samples. The two tailed significance value is $p = 0.001$, which is less than 0.05.

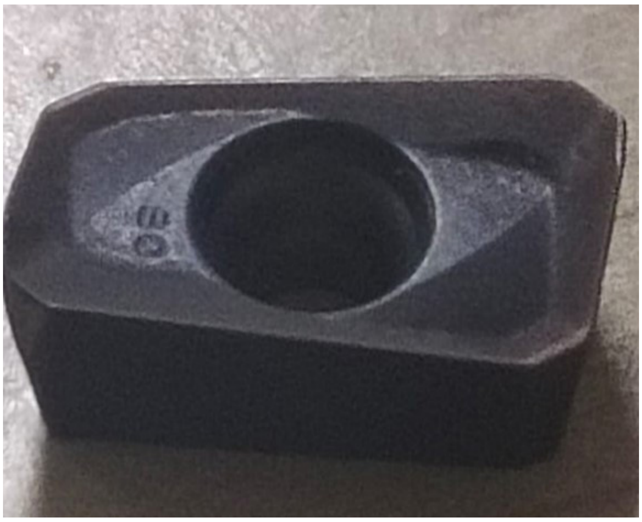

Figure 4: Flank wear of the tool insert.

Discussion

In this study, it was notices that tool wear has been reduced while cryogenic machining technique has been implemented when compared with dry machining i.e., without any coolant while machining the work material. The cryogenic machining reduces the temperature in the cutting zone which leads to reduction in the tool wear. The tool wear has been measured with Metzer microscope. The imageJ software is used to measure the tool wear from the microscopic images.

The obtained results were compared with similar kinds of research work. In this study, MQL delivers a minimal amount of lubricant directly to the cutting zone, reducing the friction between the cutting tool and workpiece. This lubrication film acts as a barrier that prevents direct metal-to-metal contact, thereby lowering the abrasive wear on the tool's flank surfaces. Attanasio et al. [16] concluded that 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. Khalil et al. [17] investigated 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

Figure 5: Metzer microscope.

Table 2: Descriptive table representing mean and standard deviation of flank wear of the tool insert of dry machining and machining with cryogenic machining technique.

Group statistics					
	Group	N	Mean	Std. deviation	Std. error mean
Roughness	CG	20	2.3740	0.08488	0.01898
	EG	20	1.5275	0.21990	0.04917

Table 1: Obtained flank wear of the tool insert values from dry machining and cryogenic machining technique.

Sample no.	Tool wear in mm	Sample no.	Tool wear in mm	Sample no.	Tool wear in mm	Sample no.	Tool wear in mm
1	1.383	11	1.306	1	0.378	11	0.441
2	1.416	12	1.312	2	0.364	12	0.462
3	1.312	13	1.116	3	0.357	13	0.487
4	1.231	14	0.987	4	0.417	14	0.411
5	1.145	15	0.912	5	0.391	15	0.462
6	0.973	16	0.892	6	0.431	16	0.402
7	0.876	17	1.316	7	0.371	17	0.384
8	0.721	18	0.993	8	0.496	18	0.396
9	0.689	19	1.262	9	0.451	19	0.405
10	1.112	20	0.212	10	0.392	20	0.367

Table 3: Descriptive table representing Levene's test for equality and t-test for equality of means. Independent sample T-test is performed for the two groups for significance p = 0.001, which is less than 0.05. Therefore, there is a statistically significant difference between the groups.

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	29.525	0.022	8.597	38	0.000	< 0.001	0.000	0.84650	0.7398	0.95920
Equal variances not assumed	-	-	16.060	24.538	0.000	< 0.001	0.84650	0.05271	0.73784	0.95516

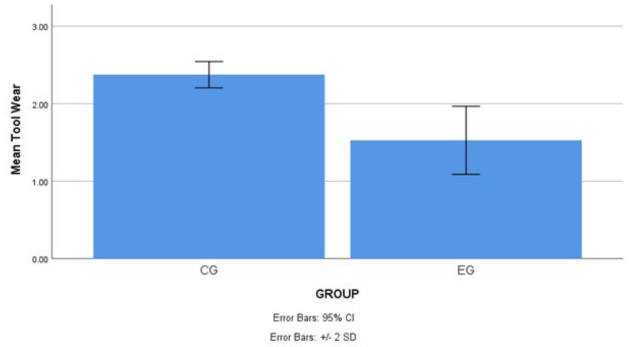

Figure 6: Mean tool wear comparison of machined surface from dry machining and cryogenic machining technique using bar graphs. SR for machined surface from dry machining is 2.3740 with a standard deviation of 0.08488 and the SR for machined surface obtained in the cryogenic machining technique is 1.5275 with a standard deviation of 0.21990. 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 cryogenic machining technique has a better surface finish with a significant lower error deviation.

flank surfaces, which can lead to accelerated wear. conducted experimental work and commented 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. It was observed minimal flank wear and crater wear were simulated [18]. Cryogenic machining to characterize micro mist droplet size and distribution [19]. 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. There is no opposite finding related to this research work.

The factors affecting this study are flow rate of Co_2 gas, atmospheric pressure, and nozzle diameter. 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 minimizes flank wear through reduced friction, efficient heat dissipation, improved chip evacuation, and sustainable lubrication practices. These advantages make MQL an attractive choice for enhancing tool life and optimizing machining processes while minimizing the detrimental effects of flank wear.

Conclusion

Within the limits of study, the effect of a novel cryogenic machining technique using Co_2 gas on tool wear of the tool insert on machining of SDSS has been studied. Considering the critical need for sustainable manufacturing practices, MQL emerges as a promising technique to usher in the era of 'green machining.' By strategically introducing a minimal quantity of lubrication right at the tool-workpiece interface, MQL not only enhances machining performance but also significantly reduces the environmental impact. It curbs excessive heat generation and mitigates tool wear, which contributes to improving tool life and, in turn, lowering production costs. Additionally, its sparing use of lubricant significantly cuts down on the disposal of toxic waste, a frequent byproduct of traditional flood lubrication. This profound effect on reducing ecological footprint, paired with operational benefits, underscores MQL as the preferred option for sustainable machining operations in a forward-looking manufacturing context. Therefore, the adoption of MQL is a significant stride towards a more sustainability-focused industry, underlining its value to enterprises pursuing a 'green' agenda. 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 the study, there is a 65% reduction in tool wear when the cryogenic machining technique has been implemented over dry machining. The cryogenic machining technique helps us to achieve sustainable production.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Su Y, He N, Li L. 2010. Effect of cryogenic minimum quantity lubrication (CMQL) on cutting temperature and tool wear in high-speed end milling of titanium alloys. *Appl Mech Mater* 34: 1816-1821. https://doi.org/10.4028/www.scientific.net/AMM.34-35.1816
2. Dos Santos AG, Da Silva MB, Jackson MJ. 2018. Tungsten carbide micro-tool wear when micro milling UNS S32205 duplex stainless steel. *Wear* 414: 109-117. https://doi.org/10.1016/j.wear.2018.08.007
3. Fernández D, Sandá A, Bengoetxea I. 2019. Cryogenic milling: study of the effect of Co_2 cooling on tool wear when machining Inconel 718, grade EA1N steel and gamma TiAl. *Lubricants* 7(1): 10. https://doi.org/10.3390/lubricants7010010
4. Bordin A, Bruschi S, Ghiotti A, Bariani PF. 2015. Analysis of tool wear in cryogenic machining of additive manufactured Ti6Al4V alloy. *Wear* 328: 89-99. https://doi.org/10.1016/j.wear.2015.01.030
5. Bruschi S, Ghiotti A. 2018. Cryogenic Machining of Titanium Alloys. Machining of Light Alloys. CRC Press.
6. Leelakar K, Kumar BN, Arul K. 2022. A review on design analysis and fabrication of body framing and chassis developing of electrical ATV. *Mater Today Proc* 51: 1030-1034. https://doi.org/10.1016/j.matpr.2021.07.082
7. Szczotkarz N, Mrugalski R, Maruda RW, Królczyk GM, Legutko S, et al. 2021. Cutting tool wear in turning 316L stainless steel in the conditions of minimized lubrication. *Tribol Int* 156: 106813. https://doi.org/10.1016/j.triboint.2020.106813
8. Hong SY, Ding Y. 2001. Cooling approaches and cutting temperatures in cryogenic machining of Ti-6Al-4V. *Int J Mach Tools Manuf* 41(10): 1417-1437. https://doi.org/10.1016/S0890-6955(01)00026-8
9. Sen B, Gupta MK, Mia M, Mandal UK, Mondal SP. 2020. Wear behaviour of TiAlN coated solid carbide end-mill under alumina enriched minimum quantity palm oil-based lubricating condition. *Tribol Int* 148: 106310. https://doi.org/10.1016/j.triboint.2020.106310
10. Vijayarangam J, Kumar BN, Vasudevan A. 2020. Simplified analysis of a multiproduct newsboy problem using simulation. *IOP Conf Ser Mater Sci Eng* 988(1): 012089. https://doi.org/10.1088/1757-899X/988/1/012089
11. Dambatta YS, Sayuti M, Sarhan AA, Hamdi M. 2018. Comparative study on the performance of the MQL nanolubricant and conventional flood lubrication techniques during grinding of Si_3N_4 ceramic. *Int J Adv Manuf Technol* 96: 3959-3976. https://doi.org/10.1007/s00170-018-1689-3
12. Sivakumar S, Kumar BN. 2023. Enhancement of bending strength of polyurethane foam reinforced with basalt fiber with silica nanoparticles in comparison with plain polyurethane foam. *Mater Today Proc* 79: 69-74. https://doi.org/10.1016/j.matpr.2022.08.343
13. Kang H. 2021. Sample size determination and power analysis using the G* Power software. *J Educ Eval Health Prof* 18. https://doi.org/10.3352%2Fjeehp.2021.18.17
14. Sivaiah P, Chakradhar D. 2018. Effect of cryogenic coolant on turning performance characteristics during machining of 17-4 PH stainless steel: a comparison with MQL, wet, dry machining. *CIRP J Manufac Sci Technol* 21: 86-96. https://doi.org/10.1016/j.cirpj.2018.02.004
15. Debnath S, Anwar M, Pramanik A, Basak AK. 2021. Nanofluid-Minimum Quantity Lubrication System in Machining: Towards Clean Manufacturing. In Sustainable Manufacturing. Elsevier, pp 109-135.
16. Attanasio A, Gelfi M, Giardini C, Remino CA. 2006. Minimal quantity lubrication in turning: effect on tool wear. *Wear* 260(3): 333-338. https://doi.org/10.1016/j.wear.2005.04.024
17. Khalil AN, Ali MA, Azmi AI. 2015. Effect of Al_2O_3 nano lubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant. *Procedia Manufac* 2: 130-134. https://doi.org/10.1016/j.promfg.2015.07.023
18. Vasudevan A, Kumar BN, Depoures MV, Maridurai T, Mohanavel V. 2021. Tensile and flexural behaviour of glass fibre reinforced plastic–aluminium hybrid laminate manufactured by vacuum resin transfer moulding technique (VARTM). *Mater Today Proc* 37: 2132-2140. https://doi.org/10.1016/j.matpr.2020.07.573
19. Rajendran S, Vasudevan A, Balaji G. 2020. Aerodynamic braking system analysis of horizontal axis wind turbine using slotted airfoil. *Mater Today Proc* 33: 3970-3979. https://doi.org/10.1016/j.matpr.2020.06.334