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Study the Influence of Novel Minimum Quantity Lubrication Technique on Tool Wear of Milling of PH17-4 Stainless Steel in Comparison with Dry Machining

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Abstract

The objective of this work is to reduce the tool flank wear of the cutting tool while machining the PH17-4 stainless steel using a minimum quantity lubrication (MQL) and compare it with tool flank wear of the tool used in the dry machining process. Two groups were considered for the study, i.e., control group and the study group. The number of samples is calculated using a sample calculator. Twenty samples were taken for each group. In the control group, the machining operation is carried out on PH17-4 without any kind of lubrication. In the experimental group using novel MQL technique, the compress lubricant is applied to the machining zone. The tool wear of the tool of each group is measured by a microscope. The results were analyzed to understand the influence of MQL. The tool wear of the samples from novel MQL is lesser than the samples obtained from the dry machining operation. The significant value obtained is p = 0.000, which is less than 0.05. It was concluded that there was 32% reduction in tool wear when the MQL technique was implemented over dry machining.

Keywords

Novel minimum quantity lubrication technique, PH17-4 stainless steel, Tool wear, CNC machining, Dry machining, SPSS software, Sustainable production

Introduction

Cutting fluids, also known as coolants, or cutting lubricants, play a critical role in machining operations. It improves cutting performance and extends tool life. Here are some notes on cutting fluids in machining [1]. One of the primary roles of cutting fluids is to dissipate the heat generated during machining. This not only protects the tool and workpiece from thermal damage, but also maintains dimensional accuracy as excessive heat can lead to material expansion [2]. There are various types of cutting fluids used in machines, including oils, emulsions, and synthetic fluids. Each type has its advantages and disadvantages [3]. Cutting fluids lubricate the contact area between the tool and the workpiece. This decreases friction which, in turn, decreases the amount of energy needed for the cutting operation, reduces cutting forces, and helps prolong the tool life [4]. Tool wear is unavoidable which leads to tool failure in the machining process. The tool wear has a strong influence on dimensional accuracy and surface finish obtained. The cutting tool wear is classified into flank wear, crater wear and corner wear. Chinchanikar and Choudhury [5] confirmed that the fluid can help flush away the cut chips from the tool/workpiece interface, preventing them from being recut or hindering the cutting process. Wang et al. [6] stated that by reducing heat and friction, cutting fluids can enhance the surface quality of the workpiece, resulting in a more precisely machined part. During machining operations, a lot of heat is generated due to the friction between the tool and workpiece. The fluids act as a coolant, reducing the temperature and preventing tool damage due to

overheating. Hamano et al. [7] pointed out that cutting fluids provide lubrication at the interface between the tool and the workpiece, thus reducing friction. Reduced friction leads to smoother cutting action and hence, a better surface finish is achieved. Cutting fluids help to dissipate the heat generated during machining. This prevents the tool from overheating, which can cause changes in the tool's geometry and lead to a rough surface finish. Furthermore, preventing excessive heat also ensures the workpiece does not expand or warp, affecting the final dimensions and surface quality. The fluids aid in flushing away cut chips from the cutting zone. This prevents chip recutting or adhesion which can mar the surface finish. Szczotkarz et al. [8] suggested that Cutting fluids help prevent the formation of built-up edge (material accumulation on the tool edge due to high pressure and temperature). This built-up edge, if formed, can break off irregularly, causing waviness or roughness on the machined surface.

The total number of research papers published related to this work and sustainable production was 18300 in google scholar and 6124 in ScienceDirect in the past ten years. Jabbaripour et al. [9] analyzed the correct application of cutting fluids can have a significant impact on achieving a good surface finish in machining operations. However, the type of fluid used should be carefully chosen as the level of improvement can depend on the fluid's properties [10]. Machining processes produce a significant amount of heat due to the friction between the cutting tool and the workpiece. Cutting fluids help absorb and dissipate this heat away from the cutting area, preventing overheating. This improves the tool life and aids in maintaining the dimensional accuracy of the workpiece [11]. Cutting fluids act as a lubricant at the interface between the tool and the workpiece. This reduces friction, resulting in smoother cutting action, reduced energy consumption, and less wear on the tool. Fluids help to wash away the chips that are cut off during the machining process. The removal of these chips prevents them from interfering with the ongoing cutting, contributing to a smoother process and a better surface finish on the workpiece. Szczotkarz et al. [8] and Nagaraj et al. [12] concluded that built-up edge refers to the accumulation of workpiece material on the cutting edge of the tool, which often occurs due to high pressure and temperature during cutting. Cutting fluids prevent the formation of this built-up edge, thus contributing to a better surface finish and improved tool life [13]. Some cutting fluids also provide protection against corrosion and oxidation, thus preserving the integrity of both the tool and the workpiece. He concluded that the effectiveness of the cutting fluid can depend on proper application and maintenance. Factors like fluid type, concentration, application method, and system cleanliness can significantly affect the performance benefits provided by cutting fluids. It was considered that Szczotkarz et al. [8] research work is closely related to this research work.

According to the findings of the research, only a limited work has been conducted on the influence of MQL on tool wear of the PH17-4 stainless steel [14]. The experimental and depth theoretical knowledge about various machining operations, MQL technique, tool wear measurement techniques, metals and alloys and interest towards sustainable production motivated me to carry out this research work [15]. This research work is focused on the surface roughness (SR) of the machining of PH17-4 stainless steel under different machining conditions [16].

Materials and Method

The CNC machining operation without any kind of lubrication is considered a control group. The machining operation using a novel MQL technique i.e., the compressed lubricant is applied to the machining zone is considered an experimental group. To obtain better results, a number of samples have been taken. The number of samples is calculated using a sample calculator [10]. In robust statistical research, appropriate determination of the sample size is crucial and can be calculated using a sample size calculator. The computation process requires four principal variables: the population size, margin of error, confidence level, and expected proportion. The total population size corresponds to the number of individuals within the demographic that the study pertains to. The chosen margin of error, typically labelled as the confidence interval, indicates a permissible degree of randomness in the survey outcomes. Subsequently, the confidence level, primarily set at 90%, 95%, or 99%, represents an estimate of the probability that the population's responses will fall within this margin. The expected proportion or rate of response is an anticipated outcome of the survey. After ascertaining these values, they are input into the sample size calculator. The result is the minimum sample size needed for the study's results to be reflective of the larger population within the desired confidence level and margin of error. As sample sizes can't incorporate fractional individuals, it's essential to round up the final figure. Determining sample size through this methodology can contribute to generating statistically significant results within the established tolerance [17].

For the control group, the machining operations are performed without lubrication. It is called dry machining. For this study SPH17-4 stainless steel is taken as a study material [18]. 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 PH17-4 stainless steel material. For the control group, the machining operations are performed without lubrication. It is called dry machining.

For the experimental group, the machining operations are carried out with MQL set up (Figure 1) [3]. The lubricant is prepared by mixing graphene nanoparticles with castor oil. The lubricant is compressed with the help of the compressor and supplied through the nozzle at the cutting zone. The set-up is shown in figure 2. The tool inserts are preserved for measuring the flank and crater wear.

The CNC machining operation has been performed using CNC lathe machining center EV 1020A which is shown in figure 3. Based on the literature survey, the machining parameters are kept as follows. 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 MQL set-up is fitted,

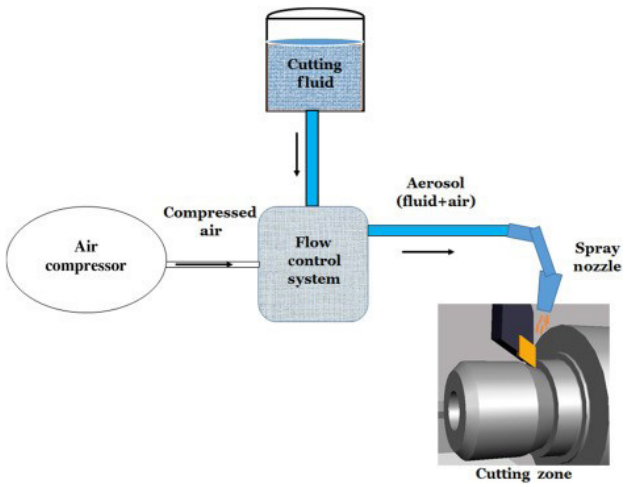

Figure 1: MQL set-up line diagram.

Figure 2: MQL set-up.

Figure 3: CNC lathe super jobber.

and the end milling operation was performed under novel MQL technique for the experimental 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 allows accurately measure tool wear. The tool inserts were kept on the measuring platform. The microscopic images were captured. Then the images were exported to ImageJ software. For more precise and accurate measurements of flank wear, a practical approach involves utilizing a toolmaker's microscope. This instrument magnifies the flank, making the wear land, or worn-out area, clearly visible and effectively measurable. The cutting tool insert should be fitted onto the stage of the microscope, aligning the focus to provide a well-resolved image of the flank. The incorporated scale within the microscope permits accurate quantification of the length of the wear land. This method, therefore, allows detailed characterization of the tool's wear pattern, which is vital in understanding not only

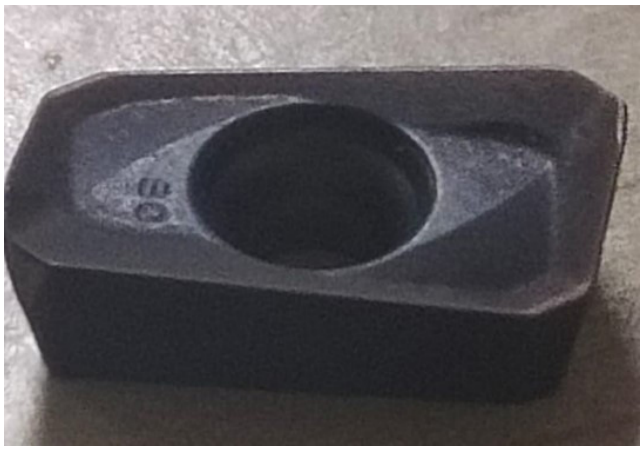

Figure 4: Flank wear of the tool insert.

Figure 5: Metzer microscope.

the severity of wear but also the wear mechanism itself. The reliable and accurate inferences derived from the use of a toolmaker's microscope for flank wear measurement denote its significance in enhancing the precision and adequacy of tool wear monitoring. The tool wear of the samples is tabulated in table 1.

Statistical analysis

For all the 20 samples of tool inserts used for machining PH17-4 stainless steel machined in dry condition and 20 samples of surface tool wear of the tool inserts under MQL technique. 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% [19]. Performing statistical analysis using the statistical package for social sciences (SPSS) software has proven highly advantageous in a range of academic research. The elevated degree of data organization, data transformation, and the possibility of running both descriptive and inferential statistical tests have been exceedingly valued. Before the analysis itself is conducted, raw data is input into an SPSS data view window, primarily resembling a spreadsheet. Data must be carefully coded, with variables clearly defined and assigned a respective scale of measurement in the variable view tab. Common descriptive statistics such as mean, median, and mode can be computed with ease, along with inferential statistics including correlation coefficients, regression analysis, t-tests, and ANOVA. The software also allows visual representation of data, facilitating its understanding. Ease of use and robustness make SPSS an effective tool for performing complex statistical analyses, offering valuable insights into the collected data.

Results and Discussion

The tool wear of the samples from the control group and study group were measured using metzer optical microscope. The tool wear of both group tool inserts 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 tool insert of the dry machining is 2.2870 with a standard deviation of 0.11291 and the mean tool wear of the for machined surface obtained in the MQL technique is 1.5560 with a standard deviation of 0.22698. The bar graph is shown in figure 6. The X axis denotes method of machining technique and Y axis denotes the mean tool wear of the. This graph shows that the machined surface obtained in the MQL technique has a better surface finish with a significantly lower error deviation.

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

Flank tool wear	N	Mean	Std. deviation	Std. error mean
Control group	20	2.287	0.1129	0.0252
Experimental group	20	1.556	0.2269	0.0507

The results prove that surface finish has been improved in the MQL machining compared to dry machining. The mean tool wear of the dry machining is 2.287. The mean surface tool wear of the MQL machining is 1.5560 which is evident that surface finish has improved. Table 3 shows the levene's test for equality and t-test for equality of means independent samples.

In this study, it was observed that SR has been reduced

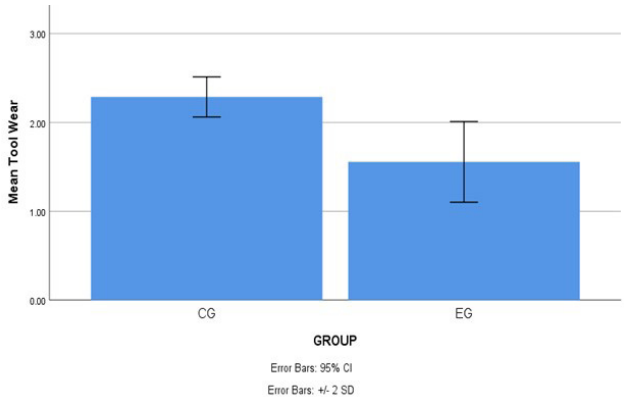

Figure 6: Mean surface tool wear comparison of machined surface from dry machining and MQL technique using bar graphs. The SR for machined surface from dry machining is 2.2870 with a standard deviation of 0.11291 and the SR for machined surface obtained in the MQL technique is 1.5560 with a standard deviation of 0.22698. 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 SD ± 2.

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	2.34	11	2.48	1	1.82	11	1.55
2	2.42	12	2.4	2	1.68	12	1.58
3	2.12	13	2.41	3	1.36	13	1.22
4	2.3	14	2.18	4	1.48	14	1.81
5	2.24	15	2.23	5	1.56	15	1.92
6	2.4	16	2.16	6	1.84	16	1.12
7	2.16	17	2.18	7	1.83	17	1.36
8	2.18	18	2.22	8	1.74	18	1.4
9	2.23	19	2.36	9	1.67	19	1.34
10	2.32	20	2.32	10	1.42	20	1.42

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

Independent samples test	Levene's test for equality of variances		T-test for equality of means						
	F	Sig.	t	df	Significance (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
								Lower	Upper
Equal variances assumed	10.098	0.003	12.895	38	0	10.4000000	1.0531107	12.2680889	13.8178687
Equal variances not assumed	-	-	12.895	27.860	0	14.4000000	1.0531107	12.2523904	13.8178689

while MQL technique with the help of graphene nanoparticles has been implemented when compared with dry machining i.e., without any coolant while machining the monel material. The MQL technique minimizes the friction between the cutting tool and workpiece which leads to minimizing the surface irregularities.

The obtained results were compared with similar kinds of research work [20]. The usage of MQL techniques presents significant implications on the surface finish of machined parts. MQL techniques aim to provide an optimal amount of cooling and lubrication by precisely applying a minute amount of lubricant, aspiring to achieve the most favorable machining performance. These techniques are known for their potential to reduce friction and heat generation at the cutting zone, consequently leading to an improved surface finish. Attanasio et al. [21] concluded that MQL also helps in deterring the welding of work material onto the tool surface, a common cause contributing to SR. The consistently formed lubricating film between the tool and the workpiece tends to minimize the abrasive and adhesive wear on the cutting tool, further reducing the likelihood of surface imperfections. Khalil et al. [22] found that the optimally targeted and reduced usage of lubricant brought by MQL minimizes the chances of the lubricant infiltrating the machined surface, which can sometimes cause texture variations and other finishing issues [23]. The effects of MQL on surface finish can significantly depend on numerous factors including the material being machined, the type of lubricant used, the tool material, and the machining parameters. Thus, the benefits of MQL techniques should be evaluated in a context-specific manner. The experimental work by researchers proposed that by delivering a minimal amount of lubricant specifically to the cutting zone, largely lessening the temperature within the cutting zone due to decreased friction. This precise application of lubricant creates a thin film between the cutting tool and the workpiece, effectively reducing the direct contact between them, hence lowering the tool wear and the heat produced. Wika et al. [24] simulated MQL and suggested that reduction in heat and friction translates to an improved surface finish as there are fewer thermal distortions and lesser likelihood of the work material adhering to the cutting tool, factors that often contribute to a rougher finish. Moreover, the cooling effect prevents the tool from reaching conditions that could lead to the softening of the tool material and consequent premature tool failure.

The MQL also aids in ejecting the chips away from the cutting zone. This chip removal prevents the chips from interfering with the cutting process and thus reduces the chances of creating surface artifacts on the workpiece. Overall, the central mechanism of MQL revolves around reducing friction and cooling the tool and workpiece to achieve an optimum surface finish. Nevertheless, it's also important to consider the other machining parameters in order to fully exploit the benefits of MQL techniques.

Conclusion

Within the limits of study, the influence of a novel MQL technique on flank wear on machining of PH17-4 stainless steel has been studied. The tool wear of novel MQL machining was compared with the tool wear of the dry machining process. It concluded that there was a 32% improvement in the surface finish when the novel MQL technique was implemented over dry machining. The future scope of MQL is promising and expansive, particularly in the sustainable manufacturing industry. As environmental concerns rise and regulatory demands tighten, MQL is viewed as a greener alternative to conventional flood cooling due to significantly reduced lubricant usage and waste disposal. Future advances may involve refining MQL systems for more precision and advanced control over the lubrication process, potentially leading to even greater efficiency and eco-friendly benefits. Additionally, integrating MQL with other innovative techniques such as nanofluid technology or cryogenic cooling could potentially enhance its effectiveness and broaden its applications. There also lies potential in exploring its use with different materials and machining operations. Thus, further research into establishing optimized parameters and determining the effectiveness of MQL under various conditions stands as an enticing prospect, potentially revolutionizing machining processes in terms of both performance and sustainability.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Tai BL, Dasch JM, Shih AJ. 2011. Evaluation and comparison of lubricant properties in minimum quantity lubrication machining. *Mach Sci Technol* 15(4): 376-391. https://doi.org/10.1080/10910344.2011.620910
2. Shinge VR, Pable MJ. 2022. Effect of nano-minimum quantity lubrication on cutting temperature and surface roughness of milling AISI D3 tool steel. *Mater Today Proc* 72(3): 1758-1764. https://doi.org/10.1016/j.matpr.2022.09.479

3. Debnath S, Anwar M, Pramanik A, Basak AK. 2021. Chapter 5 - Nanofluid-minimum Quantity Lubrication System in Machining: Towards Clean Manufacturing. In Gupta K, Salonitis K (eds) Sustainable Manufacturing. Elsevier, pp 109-135.
4. Sugihara T, Enomoto T. 2013. Crater and flank wear resistance of cutting tools having micro textured surfaces. *Precis Eng* 37(4): 888-896. https://doi.org/10.1016/J.PRECISIONENG.2013.05.007
5. Chinchanikar S, Choudhury SK. 2014. Hard turning using HiP-IMS-coated carbide tools: wear behavior under dry and minimum quantity lubrication (MQL). *Mea*surement 55: 536-548. https://doi.org/10.1016/J.MEASUREMENT.2014.06.002
6. Wang CD, Chen M, An QL, Wang M, Zhu YH. 2014. Tool wear performance in face milling Inconel 182 using minimum quantity lubrication with different nozzle positions. *Int J Precis Eng Manuf* 15(3): 557-565. https://doi.org/10.1007/S12541-014-0371-4
7. Hamano R, Costa H, de Campos Chuvas T. 2021. Influence of Cutting Conditions on Machining Forces and Tool Wear in Milling AISI304 Stainless Steel. In Proceedings of the 26th International Congress of Mechanical Engineering.
8. Szczotkarz N, Mrugalski R, Maruda RW, Królczyk GM, Legutko S, et al. 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
9. Jabbaripour B, Masouleh HS, Lavaei Salmasi MH. 2021. Comparison of surface integrity, tool wear and chip morphology in CO_2 cryogenic and dry milling of 304 stainless steel. *Surf Topogr Metrol Prop* 9(1): 015032. https://doi.org/10.1088/2051-672X%2Fabefbf
10. Barczak LM, Batako ADL, Morgan MN. 2010. A study of plane surface grinding under minimum quantity lubrication (MQL) conditions. *Int J Mach Tools Manuf* 50(11): 977-985. https://doi.org/10.1016/J.IJMACHTOOLS.2010.07.005
11. Babu MN, Anandan V, Muthukrishnan N, Santhanakumar M. 2019. End milling of AISI 304 steel using minimum quantity lubrication. *Measurement* 138: 681-689. https://doi.org/10.1016/J.MEASUREMENT.2019.01.064
12. Nagaraj N, Jule LT, Shanmugakani SK, Prakash C, Singhal P, et al. 2022. Investigation of the performance characteristics of grinding wheel using low melting vitrified bonds. *Proc Ins Mech Eng J Proc Mech Eng* 2022. https://doi.org/10.1177/09544089221132440
13. Dambatta YS, Sayuti M, Sarhan AAD. 2018. Comparative study on the performance of the MQL nanolubricant and conventional flood lubrication techniques during grinding of Si3N4 ceramic. *Int J Adv Manuf Technol* 96: 3959-3976. https://doi.org/10.1007/s00170-018-1689-3
14. Sunagar P. 2023. Characteristics estimation of natural fibre reinforced plastic composites using deep multi-layer perceptron (MLP) technique. *Chemosphere* 337: 139346. https://doi.org/10.1016/j.chemosphere.2023.139346
15. Maheswari SU. 2023. Coastal pollution analysis for environmental health and ecological safety using deep learning technique. *Adv Eng Software* 179: 103441. https://doi.org/10.1016/j.advengsoft.2023.103441
16. Britto ASF, Dattu VSNC, Al Obaid S, Alfarraj S, Kalam MA. 2023. Machining and mechanical characterization of friction stir processed (FSP) surface hybrid composites (AA8014 + TiB2 + ZrO_2). *Int J Adv Manufact Technol* 2023: 1-8. https://doi.org/10.1007/s00170-023-12198-z
17. Kang H. 2021. Sample size determination and power analysis using the G*power software. *J Educ Eval Health Prof* 18: 17. https://doi.org/10.3352/jeehp.2021.18.17
18. Öndin O, Kıvak T, Sarıkaya M, Yıldırım ÇV. 2020. Investigation of the influence of MWCNTs mixed nanofluid on the machinability characteristics of PH 13-8 Mo stainless steel. *Tribol Int* 148: 106323. https://doi.org/10.1016/j.triboint.2020.106323
19. Balazinski M, Ennajimi E. 1994. Influence of feed variation on tool wear when milling stainless steel 17-4Ph. *J Eng Ind* 116(4): 516-520. https://doi.org/10.1115/1.2902137
20. 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. *App Mech Mater* 34: 1816-1821. https://doi.org/10.4028/www.scientific.net%2FAMM.34-35.1816
21. Attanasio A, Gelfi M, Giardini C, Remino C. 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
22. Khalil ANM, Ali MAM, Azmi AI. 2015. Effect of Al_2O_3 nanolubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant. *Procedia Manuf* 2: 130-134. https://doi.org/10.1016/J.PROMFG.2015.07.023
23. Olofson CT, Gurklis JA, Boulger FW. 1967. Machining and Grinding of Ultrahigh-strength Steels and Stainless Steel Alloys.
24. Wika KK, Litwa P, Hitchens C. 2019. Impact of supercritical carbon dioxide cooling with minimum quantity lubrication on tool wear and surface integrity in the milling of AISI 304L stainless steel. *Wear* 426: 1691-1701. https://doi.org/10.1016/J.WEAR.2019.01.103