NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s3-189

Research Article

Open Access

An Experimental Investigation on Influence of Novel Minimum Quantity Lubrication Technique on Tool Wear of Milling Titanium Alloy in Comparison with Dry Machining

Yeruva Venkata Siva Nageswara Rao 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: Rao YVSN, Kumar BN. 2023. An Experimental Investigation on Influence of Novel Minimum Quantity Lubrication Technique on Tool Wear of Milling Titanium Alloy in Comparison with Dry Machining. *NanoWorld J* 9(S3): S1069-S1074.

Published by United Scientific Group

Abstract

The objective of this work is to reduce the tool wear of the cutting tool while machining the titanium alloy (Ti6A14V) using a novel minimum quantity lubrication (MQL) and compare it with tool wear of the tool used in the dry machining process. Two sets of groups were taken 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 machine operation is carried out on Ti6A14V without any kind of lubrication. In the study group using novel MQL technique, a small quantity of compressed lubricant is sprayed into the machining zone. The tool wear of the tool of each group is measured by a microscope. The effect of novel MQL technique on tool wear is studied. The tool wear of the samples from novel MQL is lesser than the samples obtained from the dry machining operation. It was found from the study that there is a 35% reduction in tool wear when the MQL technique has been implemented over dry machining.

Keywords

Ti6A14V, Tool wear, Milling, Nanoparticles, Sustainable production

Introduction

Green machines have numerous benefits for both the environment and the manufacturing industry. By reducing the environmental impact of manufacturing processes, manufacturers can reduce their carbon footprint and improve their sustainability credentials. Additionally, green machines can help reduce manufacturing costs by minimizing waste, increasing efficiency, and reducing the use of non-renewable resources [1]. The MQL technique is one of the green machining technologies. The MQL technique is a relatively new lubrication method that involves using a small amount of cutting fluid to lubricate and cool the cutting tool during machining. MQL has been found to reduce the amount of tool wear, improve surface finish quality, and reduce the environmental impact of machining operations [2]. Dry machining is a machining process wherein no cutting fluid or coolant is used. The aim of this technique is to save costs on coolant, reduce environmental impact caused using coolant, and improve the working conditions by eliminating the coolant and mist generation. It is considered to be environmentally friendly and cost-effective method [3]. Flood cooling is a common method used in machining operations where a coolant, usually a liquid, is sprayed extensively over the cutting tool and workpiece during the machining operation [1]. The coolant absorbs the heat generated by the friction during the cutting process, keeping the cutting tool and workpiece at a lower temperature. This helps to extend tool life and maintain the dimensional and structural integrity of the workpiece [3]. The liquid coolant serves as a lubricant, reducing the friction between the tool and the workpiece. This lessens tool wear and can prevent welding or adhesion of the work material to the tool. The flood of coolant helps to wash away the chips produced during the machining process, preventing them from interfering with the operation [4]. MQL presents numerous potential advantages over traditional flood cooling in machining operations. One key advantage is its substantial reduction in cutting fluid consumption, which translates to cost-effectiveness and environmental sustainability. The decreased quantity of coolant in MQL leads to markedly less cleanup and machine downtime post-machining, augmenting overall productivity [5]. MQL, in emitting less aerosol mist compared to flood cooling, creates a safer and healthier workspace. Interestingly, several studies imply that MQL can prolong tool life since the lubricant is delivered directly to the cutting edge, thus providing substantial cooling where needed most. Notably, waste creation is minimal in MQL, thereby reducing the impacts and costs associated with waste disposal. The ease of integrating MQL into existing machinery makes it highly implementable. Some reports also suggest that MQL can potentially enhance the surface finish of machined parts by curbing extreme temperature changes caused by flood cooling. Nonetheless, it's important to consider the nature of the operation and materials being machined, as MQL may not be the most suitable option for all circumstances [6]. 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 [1]. The added benefit of ease of integration with existing machinery sustains its practicality in various operational setups. Lastly, 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 machine operation, it certainly presents potential enhancements in terms of cost, environmental impact, productivity, and quality of output [7].

The total number of research papers published closely related to this work and sustainable production was 18300 in google scholar and 6124 in sciencedirect in the past ten years. The aerospace industry relies heavily on the use of Ti6A14V, machining of Ti6A14V poses several challenges due to their unique material properties. Ti6A14V are known for their high strength-to-weight ratio, excellent corrosion resistance, and impressive thermal stability, which make them highly desirable in various industries such as aerospace, biomedical, and automotive. However, these advantageous properties also lead to significant difficulties during machining. The high strength of Ti6A14V, especially at elevated temperatures, results in rapid tool wear and the necessity for frequent tool replacements, which can be cost-prohibitive. Additionally, titanium's low thermal conductivity leads to heat concentration at the cutting edge during machining. This not only shortens tool life but also can detrimentally affect the dimensional accuracy and surface finish of the machined parts. Lastly, due to its high chemical reactivity, titanium tends to weld to the tool surfaces, creating a built-up edge that further exacerbates tool wear and impairs the workpiece finish. Consequently, innovative machine strategies and advanced tool materials are required to effectively machine Ti6A14V [8]. Machining Ti6A14V presents a significant hurdle in contemporary manufacturing procedures, often serving as a central focus of research and development in the industry. This challenge arises from the inherent characteristics of Ti6A14V, characterized by their high strength, limited thermal conductivity, and a pronounced tendency to harden during cutting processes. These alloys have a tendency to generate excessive heat and induce tool wear when subjected to machining, resulting in suboptimal surface finishes and shortened tool lifespans. Additionally, their chemical reactivity with cutting tools at elevated temperatures compounds these issues, necessitating the utilization of specialized cutting tools and coolants. Sharma and Meena [9] have been investigating various methodologies, including cryogenic machining, advanced tool coatings, and adaptive control techniques, to improve the machinability of Ti6A14V and unleash their full potential in critical sectors such as aerospace and medicine. This ongoing pursuit of innovative solutions highlights the importance of comprehending and addressing the intricacies associated with machining Ti6A14V, rendering it a pertinent area of inquiry within the domain of materials science and engineering [10]. Machining hard materials poses significant challenges due to their inherent material characteristics. Hard materials, which can include hardened steels, ceramics, superalloys, and certain composites, are renowned for their exceptional wear resistance, toughness, and thermal stability. These attributes, while advantageous in their final applications, create difficulties during machining processes. Because of their high hardness and toughness, these materials induce excessively high tool wear, often leading to frequent tool changes and, hence, higher costs and longer machining times. Further, the low thermal conductivity inherent in many hard materials results in high heat generation during machining, which can be detrimental to both the cutting tool and the workpiece. This heat can cause thermal deformation of the workpiece, negatively impacting dimensional accuracy and surface finish. Additionally, in the case of superalloys and other high-performance materials, their tendency towards work hardening can further complicate the machining process and exacerbate tool wear. Therefore, efficient machining of hard materials often requires the use of advanced tool materials, optimized cutting parameters, and appropriate cutting fluid strategies to manage the challenges posed [11].

The researchers are focusing on manufacturing parts and components using sustainable and eco-friendly methods. It will reduce the environmental impact of manufacturing processes while producing high-quality products. According to the findings of the research, only a few studies have been conducted on sustainable production and the influence of novel MQL technique on tool wear of the super-duplex stainless steel. The effect of lubricant, the effect of nanoparticles, and the effect of lubricant on ferrous and nonferrous materials have not been studied thoroughly. The experience and extensive theoretical knowledge of different machining procedures, MQL, tool wear measurement methodologies, and metals and alloys make it easy to focus on this work. The machining of Ti6A14V metal under various dry conditions with minimal lubrication is the subject of this investigation. It was a type of end milling machine. The purpose of this work is to look at how the minimal amount of lubrication method affects crater and flank wear.

Materials and Methods

The samples are prepared based on the ASTM specification. This research consists mainly of two groups, namely the 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 MQL technique, where the compressed lubricant is applied to the machining zone, is considered study. To obtain better results, a number of samples have been taken. The number of samples is calculated using a sample calculator. From the previous studies, the mean and the standard deviation for the study group are 8.76 ppm and 0.04, whereas for the control group they are 9.63 ppm and 0.42 [12].

In the aerospace industry, Ti6A14V is highly valued for its high strength-to-weight ratio and heat resistance, making it ideal for critical applications such as airframe and engine components. These include fan blades, compressor blades, and structural parts of the airplane that demand a lightweight material with durable mechanical properties. In the biomedical industry, Ti6A14V has been widely used in orthopedic and dental implants due to its excellent biocompatibility. This alloy does not react with the human body and can consequently be used in long-term implants without causing adverse reactions. The automotive industry also employs Ti6A14V in high-performance vehicles for components like connecting rods and valves where lightweight and high-strength materials are required to enhance performance and fuel efficiency. For this experiment, this substance was chosen. Cemented carbide with a PVD coating was used in this experiment. An end-mill cutter with a 16 mm diameter is holding this insert in place. Each experiment only makes use of one tooth. The insert has a round 10 mm diameter and a round geometry. This experiment made use of water-soluble cutting fluid. This coolant, however, can be mixed with mineral oil or a solvent. By adjusting the air pressure that was delivered and the nozzle opening, the desired coolant flow rate was reached. With a 3-axis CNC vertical machining center, all the machining tests were performed. The primary materials of Ti6Al4V are titanium, aluminum, and vanadium, which make up approximately 90%, 6%, and 4% of the alloy by weight, respectively. Other trace elements, such as iron, oxygen, carbon, and nitrogen, may also be present in small amounts depending on the manufacturing process used. Titanium is a strong and lightweight metal that has excellent corrosion resistance, making it ideal for many applications in harsh environments. Aluminum is also lightweight and adds strength to the alloy, while vanadium improves its high-temperature strength and toughness.

For the control group, the machining operations are carried out without coolant which is termed as dry machining. The Ti6A14V workpiece material 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 [13]. The program has been executed. The required slots were obtained by dry machining.

For the study group, the machining operations are carried out with the MQL set-up is shown in figure 1 [9]. The lubrication is prepared by mixing graphene nanoparticles with castor oil. The lubrication 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 operations have been performed using CNC lathe machining Center EV 1020A on Ti6A14V material which is shown in

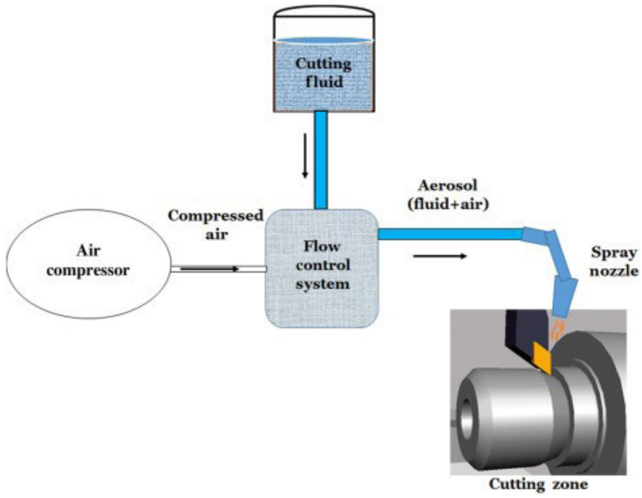

Figure 1: MQL set-up line diagram.

Figure 2: MQL set-up.

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, and the end milling operation was performed under MQL 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 allows accurately measuring tool wear. The tool inserts were kept on the measuring platform. The microscopic images were captured. Then the images were exported to ImageJ software. Tool wear is measured using imageJ for all the samples i.e., control group, dry machining, and study group, and MQL technique. The tool wear of the samples is tabulated in table 1.

Figure 3: Vertical milling machine YCM XV1020A.

Results and Discussion

The flank wear of the samples from the control group and study group were measured using a metzer optical microscope. The tool wear of the two groups of tool inserts was statistically analyzed with SPSS software, and results for various tests were obtained. The results are shown in table 2. The mean tool wear of the tool insert in dry machining is 2.3055 with a standard deviation of 0.16372, and the mean tool wear of the machined surface obtained in the MQL technique is 1.4820 with a standard deviation of 0.17459. The bar graph is shown in figure 6. The X-axis denotes the method of machining technique, and the Y-axis denotes the mean tool wear of the This graph shows that the machined surface obtained using the MQL technique has a better surface finish and a significantly lower error deviation.

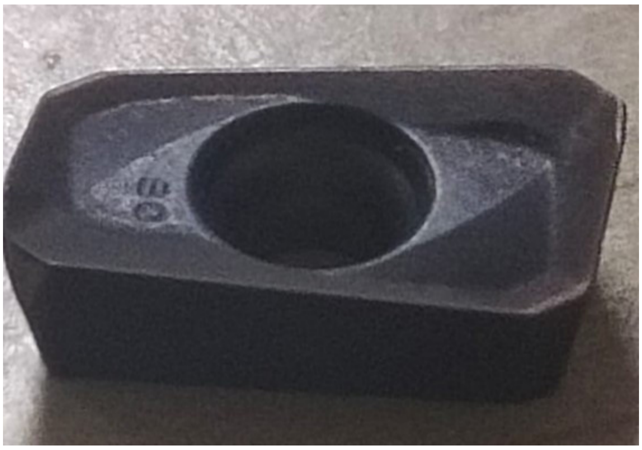

Figure 4: Flank wear of the tool insert.

The results prove that surface finish has been improved in MQL machining compared to dry machining. Dry machining has a mean tool wear of 2.3055. The mean surface tool wear of the MQL machining is 1.4820, which is evident that the surface finish has improved. Table 3 displays Levene's equality test and the t-test for equality of independent samples. The two tailed significance value is p = 0.001, which is less than 0.05. Therefore, there is a statistically significant difference between the groups.

Figure 5: Metzer microscope.

The MQL method, a sustainable manufacturing technique, has gained significant attention in recent years due to its potential to minimize heat production during machining processes. This reduction in generated heat can result in decreased tool wear and consequently, an extension in tool lifespan. The deployment of MQL coolant in the milling process of Ti6A14V was found to notably diminish tool wear and prolong cutting tool longevity compared to traditional dry machining. This is because the use of a small amount of lubricant can help reduce the amount of heat generated during the process, which in turn can lower thermal stress on the tool and reduce the adhesion of materials to the cutting edge. While MQL machining has its advantages, there are some challenges associated with its use. For example, the cost of the equipment and lubricant may be higher than that of dry machining, and the generation of the mist can pose safety and health risks to operators [14]. Moreover, the effectiveness of MQL lubrication may depend on several factors, such as the type of lubri-

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	2.56	11	2.4	1	1.76	11	1.38
2	2.54	12	2.12	2	1.74	12	1.3
3	2.48	13	2.3	3	1.68	13	1.67
4	2.44	14	2.15	4	1.62	14	1.69
5	2.38	15	2.6	5	1.5	15	1.54
6	2.26	16	2.8	6	1.52	16	1.31
7	2.24	17	2.12	7	1.56	17	1.2
8	2.5	18	2.8	8	1.4	18	1.26
9	2.16	19	2.6	9	1.43	19	1.22
10	2.14	20	2.4	10	1.46	20	1.4

Table 2: 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	2.3055	0.16372	0.03661
Study group	20	1.4820	0.17459	0.03904

cant used, the machining parameters, and the tool geometry. Therefore, it is important to carefully consider the potential advantages and limitations of MQL before implementing this machining technique. The optimization of machining parameters is crucial in reducing tool wear during the milling of Ti6A14V using MQL lubrication. The cutting speed, feed rate, and depth of cut are among the most critical parameters to consider when optimizing the machining process. High cutting speeds can lead to increased tool wear, while low feed rates can cause tool breakage. Therefore, it is important to carefully select the optimal machining parameters for each specific application [15]. The use of optimal parameters in combination with MQL lubrication can help reduce the amount of heat generated during the machining process, which can lead to less tool wear and improved surface quality. Furthermore, the environmental impact of MQL lubrication in comparison with dry machining is another important discussion point. The use of MQL lubrication can potentially reduce the amount of waste generated during the machining process, as it can eliminate the need for coolant and reduce the amount of lubricant used. This can lead to a reduction in the overall environmental impact of the machining process. However, the production and disposal of MQL lubricants may have their environmental

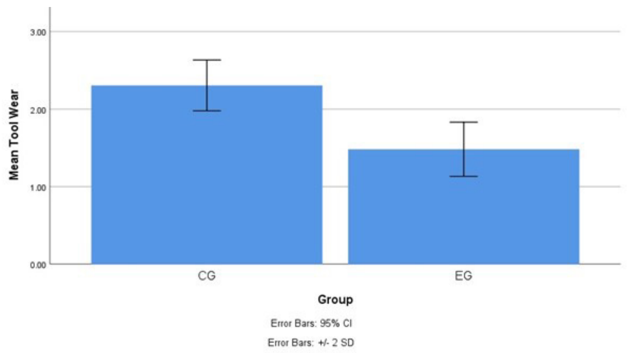

Figure 6: Mean surface tool wear comparison of dry machining and MQL techniques using bar graphs**.** The surface roughness for a machined surface obtained by dry machining is 2.3055 with a standard deviation of 0.16372, and the surface roughness for a machined surface obtained by the MQL technique is 1.4820 with a standard deviation of 0.17459. The X-axis denotes the method of machining technique, and the Y-axis denotes the mean tool wear. This graph shows that the machined surface obtained with the MQL technique has a better surface finish with a significantly lower error deviation.

impact, and it is important to carefully consider these factors when deciding whether to use MQL lubrication in the machining process. Lastly, the comparison of MQL milling with other machining techniques such as cryogenic machining and MQL with nanoparticle additives can also be explored [4]. These techniques can also reduce the amount of heat generated during the machining process, leading to less tool wear and improved surface quality. However, these techniques may have their own limitations, such as increased equipment costs, health and safety risks, and limited applicability to certain materials or machining operations.

Table 3: 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	0.051	0.022	15.387	38	0.000	0.001	0.82350	0.05352	0.71516	0.93184
Equal variances not assumed	-	-	15.387	37.844	0.000	0.001	0.82350	0.05352	0.71516	0.93184

The factors affecting this study are the weight ratio in percent of the nanoparticles, the viscosity of the vegetable oil, compressor pressure, and nozzle diameter. There is one limitation to mention because the machining operation is performed in the advanced CNC lathe machining center. In the future, researchers could investigate the effects of various nanoparticles, vegetable oils, and mineral oils. The same study can be conducted for different volume fractions of nanoparticles and varying particle sizes.

Conclusion

It is observed that the use of MQL techniques provide benefits such as reduced tool wear, longer tool life, and improved surface quality due to the reduced heat generated during the process. Overall, this research has significant implications for improving the quality and efficiency of machining processes in the manufacturing industry. The study concluded that there is a 35% reduction in tool wear when the MQL technique has been implemented over dry machining. 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.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Lin YJ, Khrais SA. 2004. Tribological influences of TiAlN coating on tool wear for high-speed dry and wet machining of steels. *Manuf Eng Mater Handl Eng* 47136: 843-848. https://doi.org/10.1115/imece2004-61574
2. Shunmugam MS, Kanthababu M. 2019. Advances in Forming, Machining and Automation: Proceedings of AIMTDR 2018. In Springer Nature, Singapore, pp 760.
3. Davim PJ. 2014. Machining of Titanium Alloys. In Springer Berlin, Heidelberg, pp 150-158.
4. Grzesik W. 2016. Advanced Machining Processes of Metallic Materials: Theory, Modelling, and Applications. Elsevier.
5. Pramanik A. 2021. Machining and Tribology: Processes, Surfaces, Coolants, and Modeling. Elsevier.
6. Nagata M, Morita H, Yamada T, Iwasa M. 2005. Approach to MQL cutting by using high lubrication cutting fluid (advanced machining technology). In Proceedings of International Conference on Leading Edge Manufacturing in 21st Century: LEM21. The Japan Society of Mechanical Engineers, pp 127-132.
7. Kannan S, Kishawy HA. 2008. Effect of tool wear progression on cutting forces and surface quality during cutting metal matrix composites. *Int J Machining Machinability Mater* 3(3/4): 296-314. https://doi.org/10.1504/ijmmm.2008.020961
8. Abele E, Hölscher R. 2014. New technology for high speed cutting of titanium alloys. In Denkena B (ed) New Production Technologies in Aerospace Industry. Lecture Notes in Production Engineering, Springer, Cham, pp 75-81.
9. Sharma S, Meena A. 2020. Microstructure attributes and tool wear mechanisms during high-speed machining of Ti-6Al-4V. *J Manuf Process* 49: 420-431. https://doi.org/10.1016/j.jmapro.2019.12.029
10. Kandelousi MS. 2018. Microfluidics and Nanofluidics. BoD – Books on Demand.
11. Nouari M, Makich H. 2014. Analysis of Physical Cutting Mechanisms and Their Effects on the Tool Wear and Chip Formation Process When Machining Aeronautical Titanium Alloys: Ti-6Al-4V and Ti-55531. In Davim J (ed) Machining of Titanium Alloys. Materials Forming, Machining and Tribology. Springer, Berlin, Heidelberg, pp 79-111.
12. Stephenson DA, Agapiou JS. 2018. Metal Cutting Theory and Practice. CRC Press.
13. 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 Manuf Sci Technol* 21: 86-96. https://doi.org/10.1016/j.cirpj.2018.02.004
14. Fan L. 2022. Comparisons of five indices for estimating local terrain surface roughness using LiDAR point clouds. In 2022 29th International Conference on Geoinformatics. Beijing, China, pp 1-6.
15. Astakhov VP, Joksch S. 2012. Metalworking Fluids (MWFs) for Cutting and Grinding: Fundamentals and Recent Advances. Elsevier.