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Experimental Investigation of Nano-Lubricants Effects on Temperature Distribution of Mild Steel Machining

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Abstract

Increasing production quality and minimizing costs in machining process have become an important aspect for green machining. In order for this to be sustained, high concern towards human health and high environmental awareness has resulted to the minimization and elimination of cutting fluids. Therefore, this research project aims at investigating the feasibility of some selected nano-particles dispersed in water as the base fluids. This is deemed a promising solution due to cooling and lubricating attributes of nano-fluids. In this case Al_2O_3, TiO_2 and SiO_2 nanoparticles were individually dispersed in water and then used to determine the variation of temperature with machining time and also the surface morphology of chip formation observed from mild steel subjected to an end milling operation in a vertical milling machine. Two pass end milling operation was carried out on the work piece while monitoring temperature response at 30 seconds interval for each trial of experiment with K thermocouple. The mean temperature distribution result obtained were 65.977ºC, 37.542ºC, 36.868ºC and 36.5796ºC for dry, TiO_2, SiO_2 and Al_2O_3 water based nano-fluids. The results showed that Al_2O_3 water base nano-coolant performed better in all the 5g/L nanoparticle concentration, nano-fluids in terms of heat transfer because it had the least mean temperature when compared to dry machining. In conclusion, 5g/L concentration of nano-coolants were efficient in machining but can be improved further by optimization.

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Keywords: End milling; Machining; Mild steel; Nano cutting fluid; Temperature

1. Introduction

Machining play a vital role in manufacturing and its significances in production industries are enormous. Machining is described as a process of removing unwanted materials (chips) from components to produce desired shape or predefined geometries [1]. According to Patil and Shinde [2], machining involves the application of cutting tools to shape, turn, mould or cut materials into desired appearances and geometries of work pieces or products. The significances of machining in modern manufacturing technology are thus justifying the investigation of machining parameters (such as cutting speed, feed rate and depth of cut), applied cutting tool and work piece materials to

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improve the economy [3].

In typical metal manufacturing processes, cutting fluids and cutting tools cost are estimated to be 7-17% and 2-4% of the total manufacturing costs respectively [4]. This is because cutting fluids and tools directly influences machined product quality. In the work of Cui et al., [5] high temperature generation at tool-chip surface during milling operations were linked to numerous negative influences, including rapid tool wear, reduction of cutting tool strength and efficiency and thus increases the requirements for cutting fluids usage in machining applications. The potential of heat generated in the cutting zones of turning and milling operation plays essential role on the final work piece quality and power consumption [6-7]. According to Wu et al, [8], milling of difficult-to-cut materials generated excessively high temperature on tool-chip interface and induced low thermal conductivity within employed coolant vis-à-vis intense friction. This invariably increases tool wear rate and degrades tool life, machining accuracy and productivity. These concerns are increasing the adoption of new cutting tool materials and cutting fluids capable of impacting improvements in material removal rates and product qualities in recent machining applications [9]. Cutting fluids also known as metal working fluids are used in machining processes as a coolant to reduce the heat generated from induced friction between the cutting tool and work piece contact surface. While, it also acts as a lubricant which minimizes the friction, cleanse chip formed during machining from the interface of the cutting tool and work piece [10]. An instance by Vasu and Kumar [11] asserted that cooling and lubrication of cutting fluids were necessary to protect work-piece and wheel from burning, while also preventing phase transformations, undesirable residual tensile stresses, thermal distortion and inaccuracies. Increasing product quality and economy of machining processes are some important aspects for green machining [12]. Development of new cutting tool designs and cutting fluids or coolants or lubricants (such as nano-fluids) having higher thermal conductivities than conventional coolants in machining applications are some of the characteristics adequately optimized to attain positive characteristics like lengthened tool life, improved surface finish and material removal rates [13]

The use of nano-fluids has been investigated to have tremendous cooling and lubricating attributes ideal for machining and is less harmful to the safety of human health and environment compared to conventional fluid, thus this study will enable us to further underline the benefits of the use of Nano fluids in machining operations as it relates to cost, energy utilized, time spent, the assurance of quality of finished work and increase in productivity as well as safety of human health and environment [14].

Ghodam [15] reviewed that temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Due to the high shear and friction energies dissipated during a machining operation the temperature in the primary and secondary shear zones are usually very high, hence affect the shear deformation and tool wear. This paper is a review of research work in last decade on temperature distribution in turning process. Zhu et al. [16] investigated that machining of steel inherently generates high cutting temperature, which not only reduces tool life but also impairs the product quality. Conventional cutting fluids are ineffective in controlling the high cutting temperature and rapid tool wear, and also they deteriorate the working environment and, hence, cause the general environmental pollution [17]. Heat-pipe-assisted cooling is an environmental friendly clean technology for desirable control of cutting temperature [18]. However, environmental hazards posed by the fluids have limited their usage, giving rise to minimum quantity lubrication. Nevertheless, its capability to carry away the heat and provide adequate lubrication is limited. In view of the above problems, nano-fluids have gained renewed interest. Nano-fluids, with their cooling and lubricating properties, have emerged as a promising solution [19-20].

Therefore, this study makes use of nanoparticles dispersed in a base fluid to form nano-fluids which is deemed a promising solution due to their cooling and lubricating attributes. The nanoparticles used in this study are graphite and multi-walled carbon nanotubes (MWCNT) were used to carry out machining operation on mild steel to study their effect on the temperature at the cutting zone.

2. Materials and Method

The material used in this study are HSS cutting tool, Mild steel material, distilled water, Al_2O_3, TiO_2 and SiO_2 nano-particles, the machining experiment was carried out using WARCO X6323A vertical Milling machine, while the beaker, Vernier calliper, Steel rule, Type-K thermocouple, Electronic weighing scale, Ultrasonic machine, and YF-4030F Image Analyser are the measuring instrument. The features of the various equipment employed, chemical composition and mechanical properties of Mild steel, Nanoparticles, Mineral oil and the fixed machining parameters used are shown in Table 1 - 4.

Table 1: Equipment Range and Measurement Characteristics

S/N	Name	Characteristics	Uncertainty of measurement
1	Vernier calliper	0 – 200 mm	± 0.03mm
2	Type-K thermocouple	-200 °C – 1260 °C	± 2.2°C

3	Electronic weighing balance	0.001g – 110g	± 0.001g
4	YF-4030F Image Analyzer	Magnification of field lens: 0.7 – 4.5x TV Total magnification: 30 – 190x	± 0.003mm
5	Steel Rule	0 – 1000 mm	±0.5mm
6	WARCO X6323A Vertical Milling machine	60rpm – 4200rpm	± 1

Table 2: Chemical composition of Mild steel

Element	Carbon, C	Iron, Fe	Manganese, Mn	Phosphorous, P	Sulphur, S
Weight %	0.17 - 0.23	99.08 – 99.53	0.30 – 0.60	≤ 0.040	≤ 0.050

Table 3: Mechanical properties of Mild steel

Density (×1000 kg/m3)	Elastic Modulus (GPa)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Poisson's Ratio
7.7-8.03	190-210	394.7	294.8	0.27-0.30

Table 4: Nanoparticles, Mineral oil characteristics and fixed machining parameters

S/N	Nanoparticle	Characteristics	Manufacturer	Parameter	Value
1	Al_2O_3	13nm	Aldrich Chemistry	Depth of cut - d (mm)	2
2	TiO_2	15nm	Alfa Aesar	Spindle speed - N (rev/min)	200
3	SiO_2	14nm	-	Feed rate – f (mm/tooth)	1
4	Mineral oil	N/A		Number of passes	2
5	Capella -D	Low carbon content Low moisture content Viscosity: 68 Flash point: 198 ºC			

2.2 Method for the Nano-Fluid Preparation Technique

A two-step nano-fluid preparation technique was employed for this investigation. The nanoparticle was carefully measured by Ohaus PA114 precision balance and then dispersed into a measured base fluid quantity (distilled water and mineral oil). A homogenized mixture was attained using a Branson ultrasonic bath for 3 hours. No surfactant or dispersant was added to the nano-fluid mixture because they were used to carry out the experiments immediately. A single mass concentration of 5g/L of base fluid was used for the preparation of nano-fluid in this study.

2.3 Material used for the experimental Setup

The experimental setup consists of a Vertical Milling machine (WARCO X6323A) with a spindle speed range from 60 – 4200rpm driven by a 2.2kW induction motor for the end milling operation on the mild steel with dimension 209mm x 60mm x 20mm [see Table 2 and 3 for chemical and Mechanical properties]. Type K thermocouple was used to monitor temperature characteristic during the end milling operation on the work piece at constant speed of 200 rpm and was positioned equidistant from the ends of the work piece width [See Table 1 for thermocouple characteristics].

A 20mm diameter end mill cutter was used for the end milling operation at a depth of 2mm in the work piece and was subjected to periodic flooding of varied composition of cooling fluids at 30 seconds interval. Employed cooling fluids composition includes:

- Al_2O_3 nanoparticles + Water.
- TiO_2 nanoparticles + Water.
- SiO_2 nanoparticles + Water.
- Dry machining.

The experiment consists of dry machining and water based nano-fluids coolant induced machining. Two pass end milling operation was carried out on the work piece while monitoring temperature response at 30 seconds interval for each trial of experiment with K thermocouple. Table 4 consists of fixed machining parameters employed for this investigation. The result of the temperature distribution and surface morphology of a 209mm x 60mm x 20mm mild steel work piece subjected to an end milling operation and coolant using varied compositions of cutting fluid added periodically were recorded.

3. Results and Discussion

The results of the experiment, for the selected machining environment is illustrated in section 3.1 and 3.2 showing the temperature variation with time in the two passes of experiment.

3.1 Temperature Variation with Time for the 1st Pass End Milling Operation.

Fig. 1-5 illustrates the temperature variation characteristics of dry, pure water based, water based nano-fluids, employed as coolant during the 1st pass of an end milling operation. The temperature distribution characteristic obtained from the use of TiO_2, SiO_2 and Al_2O_3 homogenized nano-particle dispersed in water base and dry machining for the first pass of machining. All employed water based nano-fluids temperature distributions were compared to dry machining. Results revealed that dry machining had the highest average temperature distribution than all water based nano-fluids employed for cooling. Average temperature distribution result obtained were 65.504ºC, 37.484ºC, 34.8583ºC and 34.7488ºC for dry machining, TiO_2, SiO_2 and Al_2O_3 water based nano-cooling fluids (Water based) Furthermore, TiO_2, SiO_2 and Al_2O_3 water based nano-cooling fluids had 9.76%, 9.7% and 7.15% decrease in temperature distribution when compared to dry machining of 32.90%. It was observed that discontinuous chips were formed using TiO_2 and SiO_2 with water base and dry machining while Al_2O_3 with water base produced continuous chips with built up edges. Furthermore, oxide coating was formed for all water based nano-coolants only.

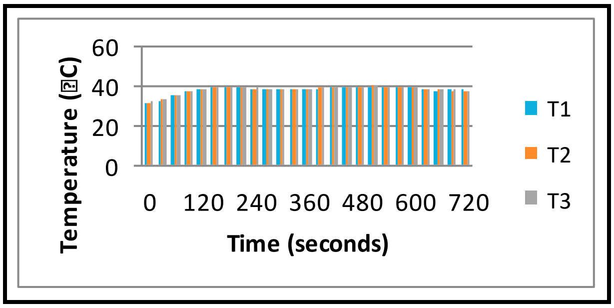

Fig 1: Temperature variation with time for the 1st pass of water based SiO_2 nano-fluid.

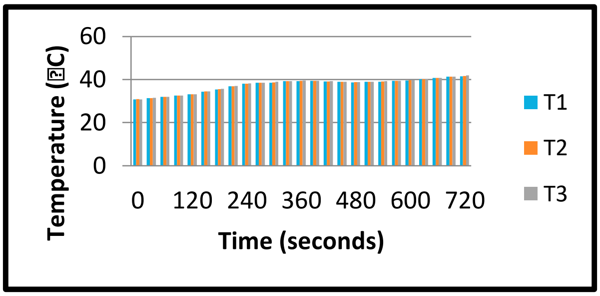

Fig. 2: Temperature variation with time for the 1st pass of water based TiO_2 nano-fluid.

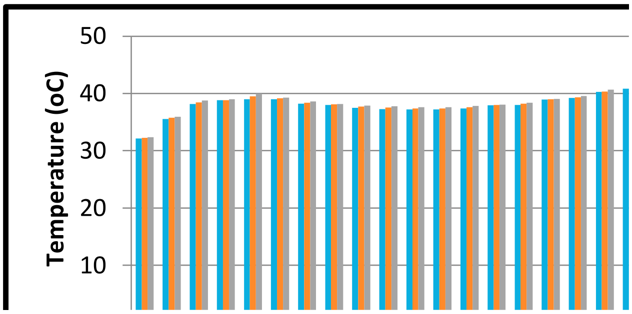

Fig 3: Temperature variation with time for the 1st pass of water based Al_2O_3 nano-fluid.

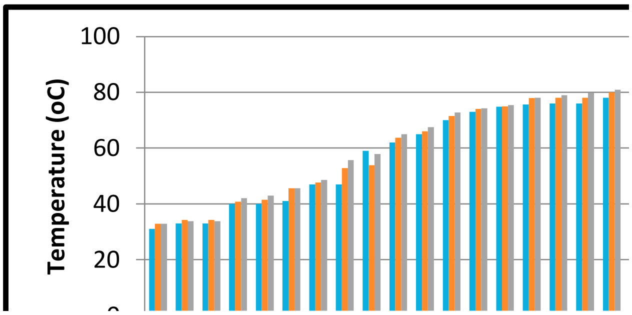

Fig. 4: Temperature variation with time for the 1st pass of dry machining.

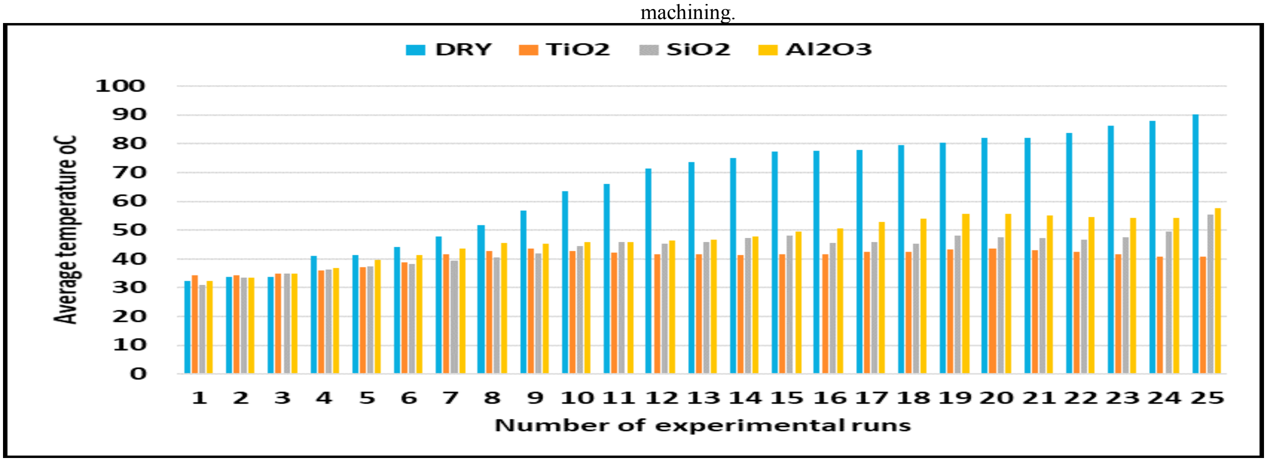

Fig. 5: Average Temperature variation with time for the 1st pass of water based SiO_2, TiO_2, Al_2O_3 nano-fluid and dry machining

3.2 Temperature Variation with Time for the 2nd Pass End Milling Operation

Fig. 6-10 illustrates the temperature variation characteristics of dry and water based nano-fluids employed as coolant during the 2nd pass of an end milling operation. It illustrates that the temperature distribution characteristic obtained from the use of TiO_2, SiO_2 and Al_2O_3 homogenized nano-particle dispersed in water base and dry machining for the second pass of machining. All employed water based nano-fluids temperature distributions were compared to dry machining. Results revealed that TiO_2 water based nano-fluid had the lowest average temperature distribution than all water based nano-fluids employed for cooling. Average temperature distribution result obtained were 37.6ºC, 38.878ºC, 38.4104ºC and 66.4507ºC for TiO_2, SiO_2, Al_2O_3 water based nano-fluids respectively and dry machining respectively. Furthermore, TiO_2 water based nano-cooling fluids had 0.29% decrease in temperature distribution when compared to dry machining while SiO_2 and Al_2O_3 water based nano-cooling fluids had 4.64% and 6.27% increase in temperature distribution when compared to dry machining, this result is in line with Okonkwo et al [21]; [22-24] compared cutting fluid with dry machining. The average temperatures of water based nano-cooling were lower than that of dry machining.

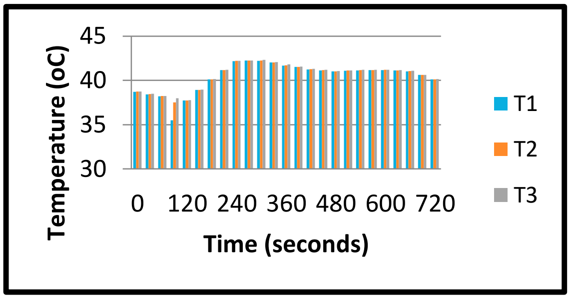

Fig. 6: Temperature variation with time for the 2nd pass of water based TiO_2 nano-fluid.

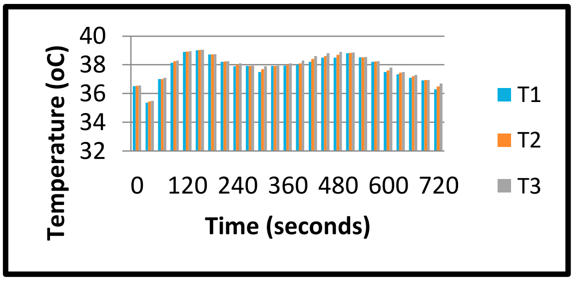

Fig. 8: Temperature variation with time for the 2nd pass of water based Al_2O_3 nano-fluid.

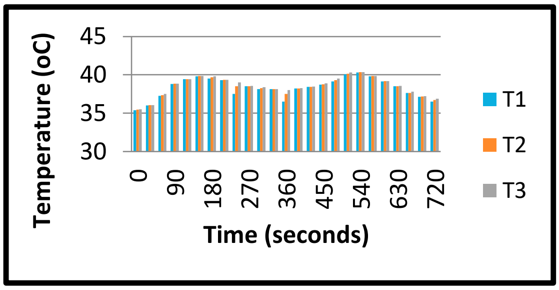

Fig. 7: Temperature variation with time for the 2nd pass of water based SiO_2 nano-fluid

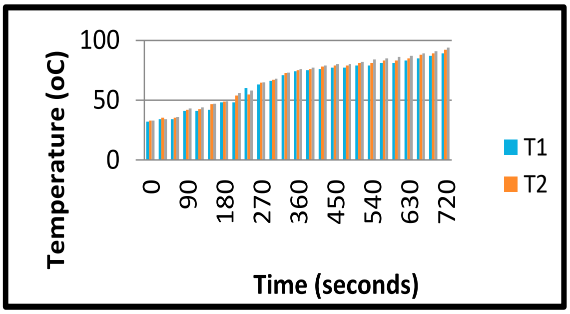

Fig. 9: Temperature variation with time for the 2nd pass of Dry machining

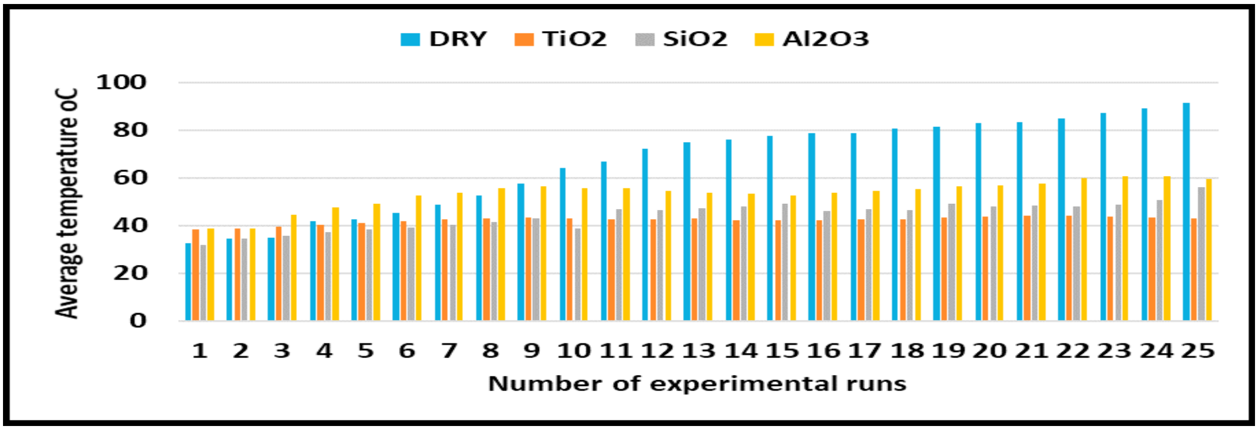

Fig. 10: Average Temperature variation with time for the 2st pass of water based SiO_2, TiO_2, Al_2O_3 nano-fluid and dry machining.

4. Conclusion

The experimental investigation study of temperature distribution characteristics using water based nano-coolants employed in an end milling operation carried out on a 209mm x 60mm x 20mm mild steel work piece revealed the following:

- All water based nano-coolant at 1st pass end milling operation had lower temperature than dry machining operation. The closest temperature distribution to dry machining was obtained using TiO_2 nano-coolant having a 7.15% reduced average temperature while Al_2O_3 nano-coolant was best having 9.76% reduced average temperature.
- 6.27% and 4.64% reduction in average temperature distribution was obtained for 2nd pass end milling operation using Al_2O_3 and SiO_2 water based nano-coolants while 0.29% increase using TiO_2 water based nano-coolant.
- Surface morphology result from image analysis showed that all water based nano-coolant formed oxide coating while all pure and nano/mineral based coolant had no oxide coat

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References

[1] O. Ogundimu, S. A. Lawal, Okokpujie IP. Experimental study and Analysis of Variance of Material Removal Rate in High Speed Turning of AISI 304L Alloy Steel. InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012030). IOP Publishing.

[2] R. A. Patil, V. D. Shinde. Performance of High Pressure Coolant on Tool Wear. *Int. J. Res. Eng. Technol*, 2013, *2*, 61-65.

[3] O. Çakīr, A. Yardimeden, T. Ozben, E. Kilickap. Selection of cutting fluids in machining processes. *Journal of Achievements in materials and Manufacturing engineering*, 2007 *25*(2), 99-102.

[4] I. P. Okokpujie, O. O. Ajayi, S. A. Afolalu, A. A. Abioye, E. Y. Salawu, M. Udo. Modeling and optimization of surface roughness in end milling of aluminium using least square approximation method and response surface methodology. International Journal of Mechanical Engineering and Technology (IJMET). 2018;9(1):587-600.

[5] C. Di, Z. Dinghua, W. Baohai, L. Ming. An investigation of temperature and heat partition on tool-chip interface in milling of difficult-to-machine materials. Procedia CIRP. 2017 Jan 1; 58:49-54.

[6] I. P. Okokpujie, O. M. Ikumapayi, U. C. Okonkwo, E. Y. Salawu, S. A. Afolalu, J. O. Dirisu, O. N. Nwoke, O. O. Ajayi. Experimental and Mathematical Modeling for Prediction of Tool Wear on the Machining of Aluminium 6061 Alloy by High Speed Steel Tools. Open Engineering. 2017 Jan 1;7(1):461-9.

[7] I. P. Okokpujie, O. S. Ohunakin, C. A. Bolu, K. O. Okokpujie. Experimental data-set for prediction of tool wear during turning of Al-1061 alloy by high speed steel cutting tools. Data in brief. 2018 Jun 1; 18:1196-203.

[8] W. Baohai, C. Di, H. Xiaodong, Z. Dinghua, T. Kai. Cutting tool temperature prediction method using analytical model for end milling. Chinese Journal of Aeronautics. 2016 Dec 1;29(6):1788-94.

[9] L. Junyan, L. Huanpeng, H. Rongdi, W. Yang. The study on lubrication action with water vapor as coolant and lubricant in cutting ANSI 304 stainless steel. International Journal of Machine Tools and Manufacture. 2010 Mar 1;50(3):260-9.

[10] I. P. Okokpujie, U. C. Okonkwo. Effects of cutting parameters on surface roughness during end milling of aluminium under minimum quantity lubrication (MQL). International Journal of Science and Research. 2015 May 31;4(5):2937-42.

[11] V. Vasu, K. M. Kumar. Analysis of nanofluids as cutting fluid in grinding EN-31 steel. Nano-Micro Letters. 2011 Dec 1;3(4):209-14.

[12] S. Sivarajan, R. Padmanabhan. Green Machining and Forming by the use of Surface coated tools. Procedia Engineering. 2014 Jan 1; 97:15-21.

[13] S. A. Lawal, M. S. Abolarin, B. I. Ugheoke, E. O. Onche. Performance evaluation of cutting fluids developed from fixed oils. LEJPT. 2007 Jan; 10:137-44.

[14] J. Sarkar, P. Ghosh, A. Adil. A review on hybrid nanofluids: recent research, development and applications. Renewable and Sustainable Energy Reviews. 2015 Mar 1; 43:164-77.

[15] S. D. Ghodam. A review of effects of temperature distribution on tool life in turning process by using finite element analysis. Int J Sci Eng Res. 2013 Oct; 1:84-7.

[16] L. Zhu, S. S. Peng, C. L. Yin, T. C. Jen, X. Cheng, Y. H. Yen. Cutting temperature, tool wear, and tool life in heat-pipe-assisted end-milling operations. The International Journal of Advanced Manufacturing Technology. 2014 May 1;72(5-8):995-1007.

[17] I. Okokpujie, U. Okonkwo, C. Okwudibe. Cutting parameters effects on surface roughness during end milling of aluminium 6061 alloy under dry machining operation. International Journal of Science and Research. 2015 Jul 31;4(7):2030-6.

[18] K. R. Sreelakshmy, A. S. Nair, K. M. Vidhya, T. R. Saranya, S. C. Nair. INTERNATIONAL RESEARCH JOURNAL OF PHARMACY.*5*(4), 239-243.

[19] R. R. Srikant, D. N. Rao, M. S. Subrahmanyam, V. P. Krishna. Applicability of cutting fluids with nanoparticle inclusion as coolants in machining. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology. 2009 Feb 1;223(2):221-5.

[20] Y. Shokoohi, E. Shekarian. Application of nano-fluids in machining processes - A review, J. Nanosci. Tech. 2016, 2(1) 59–63.

[21] U. C. Okonkwo, I. P. Okokpujie, J. E. Sinebe, C. A. Ezugwu. Comparative analysis of aluminium surface roughness in end-milling under dry and minimum quantity lubrication (MQL) conditions. Manufacturing Review. 2015 Dec 30;2(30):1-1.

[22] O. M. Ikumapayi, S. T. Oyinbo, O. P. Bodunde, S. A. Afolalu, I. P. Okokpujie, E. T. Akinlabi. The effects of lubricants on temperature distribution of 6063 aluminium alloy during backward cup extrusion process. Journal of Materials Research and Technology. 2018 Oct 22.

[23] I. P. Okokpujie, E. Y. Salawu, O. N. Nwoke, U. C. Okonkwo, I. O. Ohijeagbon, K. O. Okokpujie. Effects of Process Parameters on Vibration Frequency in Turning Operations of Perspex Material.

[24] S. A. Afolalu, O. Oluwaseyifunmi, S. O. Ongbali, A. A. Abioye, I. P. Okokpujie, O. R. Oloyede. The Study of the Impact of Nano Carbon Additives on Astm A53 Mild Steel During Machining. InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012028). IOP Publishing.