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A Review on the Application of Various MQL Base in Metal Cutting Operation of Aluminum Alloys

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Abstract:

Lubricant is an important element that acts as a cutting fluid and coolant in metal cutting processes. The function of the lubricant is to reduce the heat generated at the cutting tool-workpiece and cutting tool- chips interfaces. The heat generated at the cutting zone promotes rapid wear progression of the cutting tool which leads to high cutting force, poor surface finish and inaccurate dimensional tolerance of the component being cut. The lubricant supplied during metal cutting processes in flood machining is unfavorable as it contributes to high manufacturing cost, hazardous to machinists and contributes to environmental issues. Lubrication through Minimum Quantity Lubrication (MQL) was introduced to replace the flood cutting. MQL flow at 50ml/h to 100ml/h through the external or internal channel and sprayed towards the cutting zone. A lot of studies were conducted to observe the effect of MQL on various types of ferrous and non-ferrous metal with regards to the cutting force, surface integrity and tool wear progression during metal cutting processes. In this paper, a review of available literature on MQL applications during machining Aluminum Alloys was conducted. Factors such as MQL base and techniques, cutting parameters and cutting tools were observed to be important in the metal cutting processes. The performance, advantages and disadvantages of each study were highlighted base on the outcome of the conducted studies.

***Keywords:** Aluminum Alloy, Minimum Quantity Lubrication (MQL), Vegetable base, Water base.*

I. INTRODUCTION

Aluminum alloys are widely used in various industries such as automotive, house hold appliances, military and aerospace. This non-ferrous metal became favorable in its applications because of its high strength to weight ratio properties [1]. Metal cutting processes such as milling, turning, drilling and grinding are still relevance to achieve closer dimensional accuracy, required surface texture or finish, complex shaping, and required size. However due to its drawback properties such as high ductility promote build up edge (BUE) during metal cutting processes which require the application of lubricant as coolant during the metal cutting processes [2]. Lubricants in metal cutting help to reduce friction between tool-workpiece and tool-chip interfaces. Besides that, the lubricant also assists to reduce heat generated at the cutting zone during metal cutting processes as well as cleaning and anti-rust. Lubricants supplied through flooded machining has become a great concern to the industries in term of cost of treatment, disposal and storage of the lubricants. Another concern is the effect of lubricants

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on the safety and health of the machinist and its contribution on the current environmental issues [3].

Minimum quantity lubricants (MQL) has begun to take place to replace the flooded machining. During metal cutting process, MQL required only 10% between 3ml/h to 10ml/h during machining compared to flooded machining [4]. There are various MQL base used by the researchers in machining of Aluminum Alloys to encounter built-up-edge (BUE) and build-up-layer (BUL) due to its material ductility characteristic. BUE and BUL promote poor surface finish and reduces the tool life.

MQL setup with external applicator required a connection from compressed air which is to transport the lubricant either water or oil from reservoir through external nozzle or internal channel where the mist being sprayed directly to the cutting zone.

Common MQL technique operates when a mixture of drops of cutting fluids (neat oils or emulsions) in a flow of compressed air, generating a “spray” which is directed to the cutting region of work as lubricant and coolant through internal or external channel of nozzle depending on the cutting operations. The common flow rate of MQL supplied during metal cutting process are generally between 50 to 500 mL/h with different fluid base in machining aluminum alloys [5]. The main objective of this paper is to review the application of MQL base used in previous research in machining of Aluminum Alloys.

II. MQL BASE FOR METAL CUTTING OF ALUMINUM ALLOYS

There are several types of MQL base commonly used in metal cutting industry. They are water base, oil base, synthetic oil base, alcohol base, vegetable base and nanofluids. The application of each type of lubricant has resulted in various favorable effect on machining outputs such as satisfied tool wear progression, better surface finish compared to dry machining, lower coefficient of friction and lower cutting force. Besides that, MQL with different base required different techniques and methods in preparing the lubricant especially in nanofluids where may contributed to time consuming in machining. Other issues discussed by previous researchers are mist generation from MQL, distance of the nozzle from the cutting zone and selection of suitable cutting parameters such as cutting speed, feed rate and depth of cut for machining with MQL.

A. Water Base

Water base metalworking fluids (MWF) often consist of 5% oil and 95% water. Water base cutting fluids has great ability in cooling but relatively poor in lubrication. Water based MWF has better heat removal properties compared to MQL straight oil. In order to improve the characteristic of lubrication many researchers had made used of various additives such as silica (SiO_2), copper (Cu) and ceramic which was added in the water base cutting fluid [6].

Water based lubricant supplied through MQL in turning process of AA7075 with coated insert produced less wear at flow rate of 3.06 ml/min compared to obvious tool wear at rake face under flow rate of 0.6ml/min using Mecagree 550 lubricant after 40 min of turning process [7]. Moreover, flank wear are generally lower under MQL when turning process was done on AA6061 with the same cutting insert compared to dry machining, because MQL with water base evaporate efficiently during heat transfer [8], hence making the heat removal from the cutting tool more effective.

Wear on tool insert will lead to deterioration of surface finish of the produced components. Water base MQL helps to improve surface finish of Aluminum Alloy compared to dry and wet condition. Feed rates and lubrication conditions have direct impact on the surface finish but not the cutting speed. As shown in Fig.1 at 207 m/min of cutting speed and 0.10 mm/rev and 0.28 mm/rev of feed rate, surface roughness produced in wet condition is the highest among another two conditions, semi-dry and dry conditions. However, the surface roughness profile produced in semi-dry or known as MQL (water-based lubricant) sprayed at 3.06 ml/min is higher than the result produced in dry condition and this result is opposite at 0.1 mm/rev of feed rate. The roughness produced from semi-dry condition at 0.6 ml/min is the lowest compared to wet and dry condition at the feed rate between 0.05 to 0.10 mm/rev and the roughness is below the roughness produced in wet condition but higher than the dry condition.

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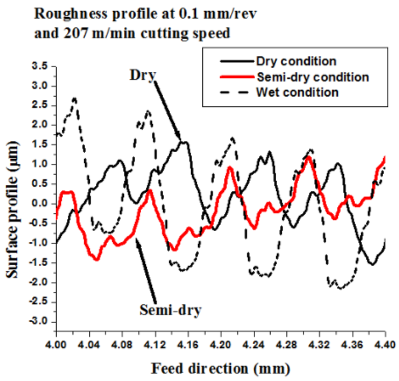

Figure 1. Surface roughness of AA6061 under different cutting condition [7]

Better roughness produced in dry condition when machining AA6061 above 0.10 mm/rev of feed rate [7]. The flank wear generated under MQL with water base is also generally lower because of lesser abrasive wear and BUE occurred on the cutting tool compared to other machining condition. However S.Islam, N. Khandoker, M. Izham, T. Azizi, and S. Debnath, 2017 proved that, the higher cutting speed leads to higher flank wear in MQL condition which produced low surface roughness.

MQL with water based used in turning process of AA7075-T6 at low flow rate of MQL could produce better surface finish in the machining process. This is proven by J. Kouam, V. Songmene, M. Balazinski, and P. Hendrick, 2015 where the authors obtained lowest surface finish at 1.75 ml/min of MQL flow rate compared to 3 ml/min of flow rate and dry turning. Boron oil-to-water with concentration of 1:10 produced better surface finish because of the lubricant with higher water concentration is more effective in lubrication and cooling at the work-tool interfaces when milling AA7075 [10].

Chip reduction coefficient is significantly lower in MQL compared to the other machining condition. Chip reduction coefficient or also known as ratio of depth of cut to the chip thickness, was expected to decrease with the increment of feed rate. However, by using water based lubricant in the machining operation, has shown the opposite result and better chip reduction coefficient could be achieved with lower flow rate (1.75 ml/min) when machining AA7075-T6 [8].

Tool breakage of uncoated HSS drill bit could be avoided because no excessive adhesion of material on the drill bit after 150th drilled holes and at maximum torque of 3.2 Nm with lesser spikes during drilling under the MQL application [11].

From the discussion above, water-based lubricant shows great performance to reduce heat generated at the cutting zone. This type of MQL lubricant is able to produce good results in term of tool wear, chip formation and surface finish, but with careful selection of MQL flow rate, cutting speed and feed rate.

B. Oil Base

Oil base as lubricant is also known as mineral oils where it is obtained from the crude oil in which the composition is very complex. The most important element of mineral oil is hydrocarbon with 30 carbon atoms in each molecule. The mineral oils are widely used as lubricant but the usage is gradually decreasing because it is non-renewable, susceptibility to explosions, oxidation at higher temperatures, loss of viscosity and furthermore it contributes to pollution of the environment [12]. The commercial oils are widely used in the machining industries to improve the lubrication at the tool-workpiece and tool-chip interfaces. Due to its high ductility, work material and chip's adhesion on the tool's surface are the two most common problems occur during machining of AA [13].

The quantity of material adhered on the tool is different for MQL, dry and flooded machining. The amount of chip material adhered to the cutting tool increased with higher cutting speed in all machining modes except flooded machining. However, MQL with BP Microtrend oil-based helps to reduce the adhesion compared to dry cutting especially with higher flow rate of MQL. Lower amount of adhered material was observed when cutting with smaller nose radius insert in turning operation of AA6061 [13].

Progression of tool wear during milling AA6061 is almost the same when machined using water-based and oil-based MQL. It is well known that machining Aluminum Alloys are most likely to get affected by cutting speed and feed rate. There was no BUE occurrence when cutting at 0.83 ml/min flow rate of both water based and oil based MQL, However, other effects such as micro welding, chipping and edge fracture as shown in Fig.2, were observed on the coated carbide insert [14]. When machining A356 with uncoated insert, the lubricant showed small influence on the flank wear, but it has been discovered that the amount of adhered material to the tool insert was reduced [15].

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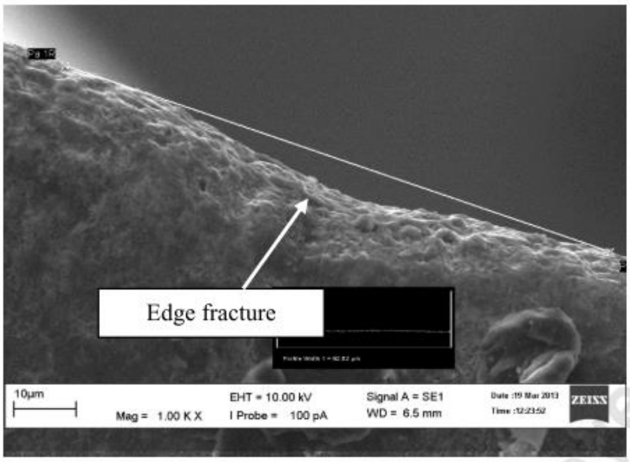

Figure 2. Edge fracture on uncoated carbide insert [14]

Mineral oil contributed to low surface roughness in turning AA6061 compared to vegetable oils although with presence of small ratio of water in both oils [16]. At high cutting speed, the use of mineral oil produced low surface finish R_a [17,18] Therefore, it can be said that the material transferred onto the machined surface could be improved through MQL application.

Eventhough oil-based lubricant have tremendous performance in machining Aluminum Alloys, the commercial oil came from non-renewable energy where its availability in the future is questionable. Limited resources will lead to price hike and cost incurred on the storage, treatment and disposing the mineral oil.

C. Vegetable Base

Vegetable oil is well known for its advantages on the environment and low toxicity towards human. Vegetable oil based lubricants being used because of its beneficial physical properties such as possessing high flash point, high viscosity index, higher lubricity, low evaporative losses, and good metal adherence [17]. It is also good solvency, load carrying capacity, low emission of hydrocarbons, higher fire resistance and good thermal properties [18].

The vegetable oil is poor in oxidation stability and flow properties because of bis-allylic carbons present between two double bonds and due to presence of saturated fatty acids. B.Sharma et al. [22] marked that 74% of major fatty acids in Moringa oil is oleic in which can improve oxidation stability without making the low temperature getting worse. Vegetable oils could be Moringa oil with Jatropha, cottonseed, canola and sunflower oil [19] and they can be classified into four categories; (1) Lauric, (2) Oleic-linoleic, (3) Eruric and (4) Riciloneic [12].

Turning AA1050 with coconut oil MQL at higher than 0.3 mm depth of cut produced better surface finish which ranged between 0.4 to 0.6 µm. However, the application of coconut and sunflower oil resulted in higher surface roughness compared to conventional oil-based lubricant when machining AA1050 [20]. Meanwhile, castor oil produced better surface finish compared to coconut and conventional oil [21].

Nozzle's distance to the cutting area is a factor that shouldn't be neglected as it also may impact the machined surface roughness of the workpiece in MQL milling of AA6061. At 45^o angle of the nozzle with various distance between the nozzle and the cutting area may lead to various result of surface roughness produced in the milling process [22].

Generally cutting force has direct relationship with cutting speed and workpiece materials especially for AA2024, AA6061 and AA7075 where lubrication has no influence on the cutting force at very high speed of machining. The measured cutting force in MQL milling at 7 mm^3/sec flow rate was nearly 600 N for AA7075 and AA6061, and above 800 N for AA2024. At low flow rate of MQL, the cutting force is the highest compared to higher flow rate as shown in Fig.3. However by increasing the flow rate of MQL, it will increases the particle emission in which may affect the machining environment [23].

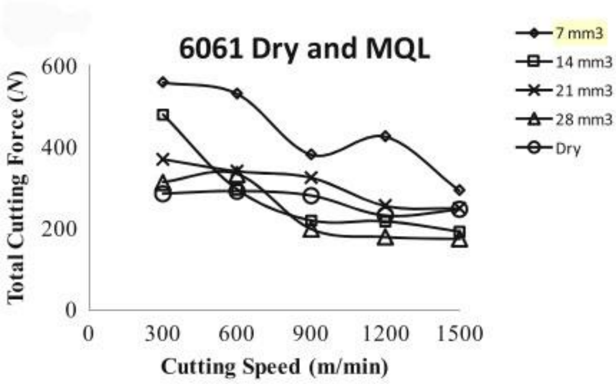

Figure 3. Distribution of cutting forces for different flow rate of MQL [23]

There are also available literatures on the research done using sesame oil, coconut oil and palm oil for the MQL application in cutting Aluminum Alloys. The vegetable oils have been proven to be a good lubrication fluid because the presence of fatty acid in the oil. Despite its good lubrication, the oils are environmentally friendly and less toxicity which

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reduce the safety and health issues on the machinists [12].

D. Nanoparticles

Nanofluids contain nanometer-sized solid particles could be from carbon nanotubes (CNTs), C60, TiO2, Al2O3,MoS2, CuO, and diamond, has been proven to provide excellent heat transfer compared to conventional fluids. The nanofluids can be produced through single-step method or two-step method, in which both methods are to disperse the metallic or non-metallic nanoparticles or nanofibers sizing at less than 100 nm in a base liquid [24].

Nanoparticles with particular size is added to base fluid to create a protective layer in the tool-workpiece interface during machining where it could reduce cutting force by applying 1 wt% nanoparticle during milling AA6061[25]. While both torque and thrust force have been reduced by the application of nano-diamond (ND) of diameter 30nm in paraffin and vegetable oil base. ND in both bases also resulted in better chips and burr removal during milling AA6061. Larger nanoparticle size seemed to produce better surface roughness in grinding especially nano Al_2O_3. Grinding temperature can be reduced by using Al_2O_3 nanoparticle because it has better lubrication compared to water base lubricants [25].

Nanoparticles in nanofluids could reduce temperature generated at the cutting zones. Application of 2 wt% of nano-diamond in MQL during drilling 7075-T6 could reduce drilling temperature because it could avoid microporous burr due to lower progression of tool wear during drilling process [26]. In addition, adequate lubrication can be seen at 210 m/min of cutting speed where lower temperature generated at the tool-chip interface due to lower friction with MQL copper-nanofluids when drilling AA5052 because diamond and copper perform as high thermal conductivity and good heat transfer coefficient [27].

Furthermore, the flank wear could be reduced with the application of copper nanoparticles in drilling of AA 5052 because the thin layer created by nanoparticles could penetrate deeper into tool material interface and produce cushion effect thus reducing the friction and cutting temperature through the increment of the cooling effect [27]. Hence, fracture on the cutting edge of drill bit could be avoided with nanofluids [26].

In turning process of AA6061 with water base nanoparticle TiO_2 MQL, the wear mechanism of the tool through fuzzy-logic base interference system showed that higher cooling rate of water and enhancement through nanoparticle improved lubricating effects. Higher MQL flow rate resulted in lesser adhesion, and lower number of nanoparticles at 0.5%, resulted in built up edge because of insufficient lubricating effect [14].

Implementing soy bean oil in drilling process with MQL machining could reduce average torque and thrust force in drilling AA6063 and the result could be further improved with aluminum oxide (Al_2O_3) nanofluid soy bean oil base. In addition, nanofluid produced better surface finished because of the nanoparticle effects on the drilled surface [28].

Chips are most likely to slide easily over the drill bit in Al_2O_3 nonaparticles fluid which prevented the chips from being welded onto the tool, thus produced better surface finish [28]. Inadequate nanoparticles could be the result of BUE during milling AA6061 especially with titanium dioxide (TiO_2) and deteriorate the surface finished [22].

The nanoparticles used in base lubricant has enhanced the cooling and lubricating effect of the base fluids. However, preparation of nanofluids required tedious efforts in determinization of its properties in term of ratio content, lubricitity and suitable nanoparticles for specific material of Aluminum Alloys.

III. CONCLUSION

A review on the various MQL base used in machining of aluminum alloys and its specific effects on the tool wear, surface roughness and cutting force is presented in this paper. According to the works reviewed in this study, MQL base used in previous works in machining aluminum alloys are from water, mineral oil, vegetable oil and nanofluids. Vegetable base and nano fluids showed promising results in cooling and lubricating the cutting zone thus contributed to lower rate of tool wear, low coefficient of friction and lower cutting force which lead to better surface roughness of machined surface.

Even though water, mineral oil and vegetable oil showed great cooling and lubricating properties, the performance has been enhanced tremendously with the appearance of nanoparticles. The nanoparticles successfully able to penetrate the cutting zone in the form of layer between the tool material interfaces.

Despites its excellent properties, nanoparticle in vegetable oil contributed to cleaner machining environment, non-toxic to machinists, reduce bad impact to environment and to the extend it could reduce manufacturing cost on the lubricant.

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REFERENCES

[1] C.-H. Ng, S. N. . Yahaya, and A. A. . Majid, "Reviews on aluminum alloy series and its applications," *Acad. J. Sci. Res.*, vol. 5, no. December, pp. 708–716, 2017.

[2] M. C. Santos, A. R. Machado, W. F. Sales, M. A. S. Barrozo, and E. O. Ezugwu, "Machining of aluminum alloys: a review," *Int. J. Adv. Manuf. Technol.*, vol. 86, no. 9–12, pp. 3067–3080, 2016.

[3] M. Omair *et al.*, "Sustainable Machining," *J. Clean. Prod.*, vol. 2, no. 5, pp. 1–18, 2017.

[4] S. Madhukar, A. Shravan, G Sreeram Reddy, and P. Vidyanand, "A Critical review on Minimum Quantity Lubrication (MQL) Coolant System for Machining Operations," *Int. J. Curr. Eng. Int. J. Curr. Eng. Technol.*, vol. 6, no. 5, 2016.

[5] A. Zainol and M. Z. A. Yazid, "Review of development towards minimum quantity lubrication and high speed machining of aluminum 7075-T6," no. May. 2018.

[6] B. L. Tai, J. M. Dasch, and A. J. Shih, "Evaluation and comparison of lubricant properties in minimum quantity lubrication machining," *Mach. Sci. Technol.*, vol. 15, no. 4, pp. 376–391, 2011.

[7] M.Balazinski, V.Songmene, J.Kouam, and P.Hendrick, "Dry, Semi-Dry and Wet Machining of 6061-T6 Aluminium Alloy," *Sch. Enviromental Sci.*, 2012.

[8] S. Islam, N. Khandoker, M. Izham, T. Azizi, and S. Debnath, "Development of a Low Cost MQL Setup for Turning Operations," *MATEC Web Conf.*, vol. 95, p. 10004, 2017.

[9] J. Kouam, V. Songmene, M. Balazinski, and P. Hendrick, "Effects of minimum quantity lubricating (MQL) conditions on machining of 7075-T6 aluminum alloy," *Int. J. Adv. Manuf. Technol.*, vol. 79, no. 5–8, pp. 1325–1334, 2015.

[10] N. Tosun and M. Huseyinoglu, "Effect of MQL on surface roughness in milling of AA7075-T6," *Mater. Manuf. Process.*, vol. 25, no. 8, pp. 793–798, 2010.

[11] S. Bhowmick and A. T. Alpas, "Minimum quantity lubrication drilling of aluminium-silicon alloys in water using diamond-like carbon coated drills," *Int. J. Mach. Tools Manuf.*, vol. 48, no. 12–13, pp. 1429–1443, 2008.

[12] W. K. Shafi, A. Raina, and M. I. Ul Haq, "Friction and wear characteristics of vegetable oils using nanoparticles for sustainable lubrication," *Tribol. - Mater. Surfaces Interfaces*, vol. 12, no. 1, pp. 27–43, 2018.

[13] P. S. Sreejith, "Machining of 6061 aluminium alloy with MQL, dry and flooded lubricant conditions," *Mater. Lett.*, vol. 62, no. 2, pp. 276–278, 2008.

[14] M. S. Najiha, M. M. Rahman, and A. R. Yusoff, "Flank Wear Characterization in Aluminum Alloy (6061 T6) With Nanofluid Minimum Quantity Lubrication Environment Using an Uncoated Carbide Tool," *J. Manuf. Sci. Eng.*, vol. 137, no. 6, p. 061004, 2015.

[15] H. A. Kishawy, M. Dumitrescu, E. G. Ng, and M. A. Elbestawi, "Effect of coolant strategy on tool performance, chip morphology and surface quality during high-speed machining of A356 aluminum alloy," *Int. J. Mach. Tools Manuf.*, vol. 45, no. 2, pp. 219–227, 2005.

[16] N. Gharaibeh, "Vegetable and Mineral Used Oils as Cutting Fluids: Effect on Surface Roughness of Aluminum Alloy," *J. Surf. Eng. Mater. Adv. Technol.*, vol. 06, no. 04, pp. 176–182, 2016.

[17] T. M. Panchal, A. Patel, D. D. Chauhan, M. Thomas, and J. V. Patel, "A methodological review on bio-lubricants from vegetable oil based resources," *Renew. Sustain. Energy Rev.*, vol. 70, no. August 2016, pp. 65–70, 2017.

[18] R. Somashekaraiah, D. P. Gnanadhas, S. P. S, S. V. Kailas, and D. Chakravortty, "Eco-Friendly, Non-Toxic Cutting Fluid for Sustainable Manufacturing and Machining Processes," *Tribol. Online*, vol. 11, no. 5, pp. 556–567, 2016.

[19] B. K. Sharma, U. Rashid, F. Anwar, and S. Z. Erhan, "Lubricant properties of Moringa oil using thermal and tribological techniques," *J. Therm. Anal. Calorim.*, vol. 96, no. 3, pp. 999–1008, 2009.

[20] P. Bhowmik, U. Kumar, G. Arora, P. G. Students, and G. Noida, "Vegetable Oil Based Cutting Fluids–Green and Sustainable Machining - I," vol. 2, no. 9, pp. 1–5, 2015.

[21] U. Kumar, A. Jamal, and A. A. Ahmed, "Performance Evaluation of Neat Vegetable Oils as Cutting Fluid during CNC Turning of Aluminium (AA1050)," *J. Mater. Sci. Mech. Eng.*, vol. 2, no. 7, pp. 70–75, 2015.

[22] M. S. Najiha, M. M. Rahman, and K. Kadirgama, *Performance of water-based TiO 2 nanofluid during the minimum quantity lubrication machining of aluminium alloy, AA6061-T6*, vol.

May – June 2020
ISSN: 0193-4120 Page No. 1168 - 1174

135. Elsevier Ltd, 2016.
[23] R. Khettabi, M. Nouioua, A. Djebara, and V. Songmene, "Effect of MQL and dry processes on the particle emission and part quality during milling of aluminum alloys," *Int. J. Adv. Manuf. Technol.*, vol. 92, no. 5–8, pp. 2593–2598, 2017.
[24] N. A. C. Sidik, S. Samion, J. Ghaderian, and M. N. A. W. M. Yazid, "Recent progress on the application of nanofluids in minimum quantity lubrication machining: A review," *Int. J. Heat Mass Transf.*, vol. 108, pp. 79–89, 2017.
[25] M. Rifat, M. H. Rahman, and D. Das, "A review on application of nanofluid MQL in machining," *AIP Conf. Proc.*, vol. 1919, no. December, 2017.
[26] W. T. Huang, D. H. Wu, and J. T. Chen, "Robust design of using nanofluid/MQL in micro-drilling," *Int. J. Adv. Manuf. Technol.*, vol. 85, no. 9–12, pp. 2155–2161, 2016.
[27] M. Naresh Babu and N. Muthukrishnan, "Experimental analysis in drilling of AA 5052 using copper nanofluids under minimum quantity lubrication," *Aust. J. Mech. Eng.*, vol. 4846, pp. 1–10, 2018.
[28] S. S. Chatha, A. Pal, and T. Singh, "Performance evaluation of aluminium 6063 drilling under the influence of nanofluid minimum quantity lubrication," *J. Clean. Prod.*, vol. 137, pp. 537–545, 2016.

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