

Turning process of aluminium alloy 7075 under minimum quantity lubrication using vetiver oil and waste cooking oil

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Keywords

turning
MQL
waste cooking oil
vetiver oil
grey relational analysis

History

Received: 16-02-2026

Revised: 22-06-2026

Accepted: 20-08-2026

Abstract

The present study investigates the machining behaviour of aluminium alloy 7075 under minimum quantity lubrication using waste cooking oil and vetiver oil as biodegradable cutting fluid alternatives to conventional mineral-based lubricants. A cobalt-enriched carbide insert was used, and experiments were designed using an L16 orthogonal array to systematically investigate the effects of the main machining parameters (spindle speed, feed rate and depth of cut). The evaluation and comparison of the performance parameters, cutting temperature, surface roughness, tool life and material removal rate were performed with dry and compressed air machining. The experimental results were used for grey relational analysis (GRA) to identify the optimal parameter set and provide an overall analysis of the results. The results showed significantly improved machining performance, especially with both oils, due to lower heat generation and better surface quality. The use of waste cooking oil was found to provide stable lubrication and enable the reuse of waste resources for minimum quantity lubrication (MQL)-assisted turning. Vetiver oil was selected for its advantageous thermophysical properties, especially its high flash point, appropriate viscosity and thermal stability. The results also showed that both waste cooking oil and vetiver oil can be used as environmentally friendly lubricants for the turning of aluminium alloy 7075. However, machining responses achieved using vetiver oil were more stable and had better overall performance.

1. Introduction

The growing emphasis on minimum quantity lubrication (MQL)-assisted turning has sparked significant interest in reducing the environmental impact of machining operations. As industries move toward green manufacturing, the choice of cutting fluids and cooling techniques has come under scrutiny due to their direct implications on waste management, energy efficiency and worker safety. In this context, MQL has emerged as a viable alternative to conventional flood cooling methods, balancing performance and sustainability. When applied correctly, MQL reduces lubricant consumption while

maintaining machining performance, especially when combined with bio-based or waste-derived oils. Aluminium alloy 7075 (Al 7075) is widely used in the aerospace and automotive industries due to its high strength combined with low weight. However, its high strength and heat sensitivity make machining difficult. Achieving improved surface roughness and longer tool life, particularly without mineral oil-based lubricants, requires adopting new, effective lubrication strategies. This study explores four Al 7075 turning conditions: dry, compressed air, waste cooking oil and vetiver oil machining, with a strong focus on environmental sustainability and circular economy principles. Pei et al. [1] demonstrated that ester-based and castor oil emulsions exhibited better lubrication and cooling performance than conventional fluids during machining of AISI 1045



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steel. At about the same time, Kilickap et al. [2] compared MQL and dry techniques for Al 7075, reporting that MQL outperformed dry and compressed air methods by 66 % in surface quality. These foundational results confirmed the practical viability of MQL for aluminium alloys. Adebayo et al. [3] conducted a study evaluating the performance of mango oil against conventional mineral oil as cutting fluids during the machining of AISI 1525 steel using tungsten carbide tools. The results indicated that mineral oil provided better outcomes, producing lower surface roughness and reduced cutting temperatures than mango oil. Kouam et al. [4] introduced Mecagreen 550, a vegetable-based lubricant mixed with water, which improved tool life while reducing aerosol emissions, an important factor in occupational health and safety. Similarly, Schuch Bork et al. [5] found that *Jatropha* oil increased tool life by nearly six times under flood cooling, while Kuram et al. [6] developed sulfonated castor oil-based fluids that were not only effective but also environmentally safer than traditional options.

Previous studies consistently demonstrate that biodegradable cutting fluid type and lubrication strategy significantly influence machining performance. Wickramasinghe et al. [7] developed a coconut oil-based metalworking fluid for biodegradable cutting fluid-assisted machining lubrication and reported notable reductions in cutting temperature and friction because the coconut-derived lubricant provided superior lubricity and thermal stability compared with conventional mineral oils. Srikant and Rao [8] reviewed multiple vegetable oil-based cutting fluids, including neem, sunflower, canola and coconut oils, primarily under MQL, and concluded that these biolubricants improved surface roughness, reduced tool wear and lowered heat generation due to enhanced boundary lubrication and biodegradability. Rosli and Zamiruddin [9] reviewed previous investigations reporting that graphene oxide nanoparticles incorporated into MQL fluids could improve tool life and reduce surface roughness during machining operations. Therefore, the conclusions presented by Rosli and Zamiruddin represent a synthesis of earlier studies rather than independent experimental findings. Kalidoss et al. [10] extended this idea by evaluating the thermal performance of Therminol 55 nanofluids, followed by studies in Kalidoss et al. [11] comparing them with silver-graphene water-based nanofluids, which showed better thermal efficiency and stability. This shift toward thermally efficient,

low-emission lubricants contributed to the broader sustainability conversation. Chavan and Sargade [12] and Gunjal et al. [13] investigated multiple vegetable oils, including coconut, soybean, cottonseed and palm oil, for MQL applications. Their findings showed that soybean oil consistently delivered the best results in terms of surface roughness and cutting force, while lower feed rates resulted in reduced surface roughness. These studies emphasised that even within bio-based options, lubricant selection and process optimisation significantly affect outcomes. Alshibi et al. [14] specifically investigated vegetable oil-based MQL in machining AZ91 magnesium alloy, where the MQL-assisted turning strategy significantly enhanced surface quality while simultaneously lowering cutting forces and temperature compared with dry machining. Kumar et al. [15] analysed nano-MQL, in which nanoparticles were dispersed in biodegradable base oils to improve cooling and tribological performance. This hybrid approach outperformed conventional MQL by improving tool life, minimising friction and stabilising machining temperatures across difficult-to-machine materials. Basmacı et al. [16] focused on hardened Inconel 718 machining and employed optimisation through grey relational analysis combined with biodegradable cutting fluid-assisted turning lubrication control, showing that properly selected eco-friendly lubrication environments improved surface roughness and reduced cutting force simultaneously.

Pires Souza et al. [17] evaluated cottonseed oil, canola oil and Quimatic synthetic fluid under MQL conditions during AISI 316 stainless steel turning. Among the tested fluids, cottonseed and canola oils reduced machining forces and improved surface quality, demonstrating their potential as sustainable alternatives to conventional cutting fluids. Farfan-Cabrera et al. [18] identified microalgae oils as a biodegradable cutting fluid-assisted machining alternative with potential scalability challenges. These investigations further diversified the pool of green cutting fluids, aligning well with the circular economy model. Parthe [19] applied rapeseed vegetable oil through MQL while machining AISI 1060 aluminium and noticed better surface quality with noticeably lower cutting forces, confirming the practical value of vegetable oil-based lubrication in biodegradable cutting fluid-assisted machining. Sen et al. [20] used blended palm and sunflower biolubricants under MQL and reported enhanced machining performance through improved surface characteristics and

reduced energy demand, with TOPSIS analysis identifying the most effective lubrication combination. Makhesana et al. [21] combined MoS₂ with vegetable oil to improve surface quality by up to 44 %, while reducing tool wear by 56 % during machining of aluminium alloy 6082, which is closely related to the Al 7075 workpiece of this study. Situmorang et al. [22] reported that palm oil-derived biolubricants exhibit favourable physicochemical and tribological properties, making them viable substitutes for conventional mineral-based cutting fluids. They also noted that incorporating natural additives enhances thermal stability and lubrication performance, supporting their application in biodegradable cutting fluid-assisted machining processes. Rajasozhaperumal and Kannan [23] tested Jatropha crude oil under MQL, reporting a 54 % reduction in tool wear and a 22 % improvement in surface roughness over dry machining, again demonstrating the potential of biooils in advanced lubrication systems.

Kazeem et al. [24] studied palm kernel oil and mineral oil as lubricants and found that mineral oil improved surface roughness by 48.2 %, while palm kernel oil reduced cutting temperature by about 0.89 %. They used a Taguchi L9 orthogonal array and grey relational analysis to optimise the machining process. Kannan and Sivaram [25] investigated machining of aluminium alloy 6063 and reported a 72.84 % reduction in carbon emissions and a 72.82 % decrease in energy consumption. The study employed an L27 Taguchi orthogonal array to optimise the process for sustainability. Kazeem et al. [26] studied the use of watermelon oil for machining of AISI 1525 steel with tungsten tools. They found that, under most test conditions, this bio-based oil performed better than mineral oil. Their models achieved accuracy between 69.73 and 99.05 %, highlighting watermelon oil's effectiveness as a biodegradable cutting fluid-assisted machining alternative. Most recently, Karthikraja et al. [27] introduced multi-walled carbon nanotubes in ionic liquids, reducing drilling temperatures by 23.18 % and improving heat transfer by 59.05 %. They concluded that eco-friendly, nanoparticle-based lubricants offer superior chip evacuation, tool life and surface roughness.

The present study offers a new perspective on biodegradable cutting fluid-assisted machining by testing two uncommon bio-based lubricants, waste cooking oil and vetiver oil, under MQL for cutting turning of Al 7075. Unlike earlier studies that mostly examined standard vegetable oils or nano-

enhanced fluids, this research evaluates lubricants that are either recovered from household waste or derived from a naturally stable essential oil. Assessing them alongside dry and compressed air machining provides a new comparison not explored for Al 7075. By demonstrating how these oils influence tool wear, temperature, surface roughness and machining efficiency, the study introduces practical, low-impact alternatives that support circular economy principles and reduce reliance on conventional mineral oils. Compared with several vegetable-based lubricants reported in previous studies, vetiver oil has a relatively higher flash point and adequate viscosity, which help maintain a stable lubricating film and reduce friction-induced heat generation. These characteristics are expected to improve tribological behaviour during turning operations.

2. Experimental procedure

2.1 Materials and methods

The aluminium alloy 7075 (Al 7075) is frequently selected for components requiring a balance between reduced weight and reliable mechanical performance under service loads [28]. In the present study, environmentally friendly cutting fluids were used for turning of Al 7075 under MQL conditions. This alloy was chosen because of its high strength (tensile strength of 580 MPa and yield strength of 500 MPa) and thermal conductivity, which generate a large amount of heat during cutting. Two lubricants were compared, i.e. vetiver oil and waste cooking oil. Vetiver oil showed better viscosity, thermal conductivity and flash point, leading to better lubrication and cooling, whereas waste cooking oil showed moderate but biodegradable cutting fluid-assisted machining performance. Table 1 illustrates the main fluid properties of waste cooking oil and vetiver oil.

Table 1. Usual cutting fluid properties [29,30]

Property	Waste cooking oil	Vetiver oil
Density, kg/m ³	920.4	1009.7
Kinematic viscosity at 40 °C, mm ² /s	31.381	933.55
Acid number, mg KOH/g	2.29	11.5
Colour	dark brown	reddish brown

Figure 1 illustrates the materials employed as the biodegradable lubricants used in the present investigation. Waste cooking oil, primarily sunflower, was collected at the domestic level and pretreated to ensure consistency. It was filtered through a fine mesh and 10 μm filter paper to remove solid impurities, then heated to approximately 60 °C to remove the remaining moisture.

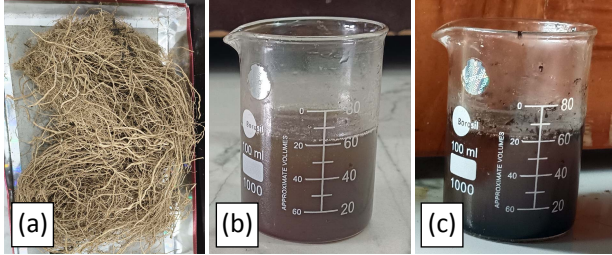


Figure 1. Materials employed as the biodegradable lubricants: (a) collected vetiver roots, (b) dark brown vetiver oil and (c) deep dark brown waste cooking oil

Vetiver roots were washed, dried under ambient conditions and ground into smaller particles before extraction. Essential oil needed for the MQL application was obtained by hydrodistillation. Mijailović et al. [31] discussed the extraction behaviour of essential oils using distillation-based methods, while Lamido et al. [32] showed that hydrodistillation methods can be used for essential oil recovery. Based on these findings, the present work employed hydrodistillation, and the extraction time and feed material quantity were optimised for this investigation. The study further noted that conventional distillation methods are energy-intensive and require prolonged processing duration. A mechanical grinder was used to grind the roots into particles with a mean size of 300 – 500 μm . A 100 g sample was hydrodistilled in a Clevenger apparatus at approximately 100 °C at atmospheric pressure over 10 hours. The condensed mixture was partitioned into the oil and the hydrosol. Approximately 0.608 ml of oil was obtained, moisture was removed, and it was stored in amber containers.

Figure 2 presents the experimental arrangement of the MQL system. It is used for turning of Al 7075 alloy with bio-based cutting fluids. Table 2 lists the machining parameters selected for the experimental study, including spindle speed, feed rate and depth of cut. Machining experiments were performed on a Sona hardened-bed lathe. MQL system supplied lubricant at a constant flow rate of 50 ml/h, with compressed air pressure maintained between 4 and 6 bar. A pneumatic atomising

nozzle with a 0.5 mm diameter, positioned at 45° and 40 mm from the cutting zone, was used to ensure effective lubricant penetration into the tool-chip interface. The generated oil mist improved cooling efficiency, reduced frictional heat generation and enhanced machining stability under biolubricated turning conditions.

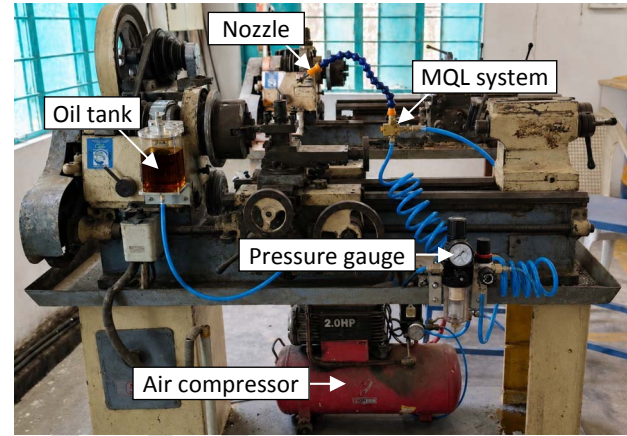


Figure 2. Experimental setup of the MQL system used for turning of Al 7075 alloy with bio-based cutting fluids

Table 2. Machining parameters

Spindle speed, rpm	Feed rate, mm/rev	Depth of cut, mm
745	0.2	0.5
1305	0.3	0.75
1850	0.4	1.0
2530	0.5	1.25

Based on comparable MQL tribology studies, the atomised droplet diameter typically ranged from 10 to 50 μm , promoting effective boundary lubrication, reducing thermal accumulation and improving machining stability. The turning experiments on Al 7075 used a TiAlN-coated carbide insert with a 10° rake angle, 7° clearance angle and 0.8 mm nose radius to improve machining stability. The cutting tool dimensions included a 12 mm cutting edge length, 4.76 mm insert thickness and 12.7 mm inscribed circle diameter mounted on a rigid PSBNR tool holder. This geometry enhanced chip evacuation, minimised frictional heat generation and improved surface roughness and tool life under MQL machining with waste cooking oil and vetiver oil.

Monitoring of cutting temperature was done on a Beetech B-IR6 infrared thermometer directed at a spot of approximately 12 mm at the tool-chip interface with an accuracy of 1.5 %. Cutting temperature was measured after 30 s of

continuous turning to ensure thermal stabilisation at the tool-chip interface under each lubrication condition. The infrared thermometer readings were taken during steady-state machining and averaged from three repeated trials to improve measurement reliability and consistency.

Surface roughness evaluation was carried out using an Rtec MFT-5000 tribometer under standardised measurement conditions. Measurements were performed with a cut-off length of 0.8 mm and an assessment length of 4 mm, using Gaussian filtering to obtain accurate surface texture characteristics. The arithmetical mean height (Ra) was used to assess machining performance. Roughness measurements were taken along the feed direction at three separate locations on the machined specimen and the mean value was used to improve consistency and reliability.

Material removal rate was calculated from the change in dimensions, measured with a digital vernier caliper (± 0.01 mm). All tests were repeated three times to improve reliability. Tool life was obtained from the experimental measurements and defined as the machining duration corresponding to an average flank wear of 0.3 mm. The objective of the study was to compare lubrication environments rather than establish a predictive tool life model. Therefore, the determination of the Taylor exponent and machining constant was beyond the scope of this work.

2.2 Grey relational analysis

Grey relational analysis was used to evaluate the combined influence of machining parameters on major performance characteristics, including cutting temperature, surface roughness, tool life and material removal rate during the turning of Al 7075. The inclusion of surface roughness enabled simultaneous assessment of machining quality and productivity, providing a balanced optimisation approach for MQL-assisted machining conditions. In the present research, grey relational analysis was used to evaluate the effects of spindle rotation speed, feed per revolution and cutting depth on the major performance results such as heat generation, surface quality, tool life and material removal efficiency.

The grey relational analysis procedure included normalisation of experimental responses, followed by computation of the grey relational coefficient and grey relational grade for multi-response

optimisation. The distinguishing coefficient ζ was introduced to regulate the sensitivity of relational comparison among the machining responses, and a coefficient value of 0.5 was selected to maintain balanced relational evaluation and numerical stability. The normalised response sequence, ideal reference sequence and deviation values used in the GRC determination were mathematically formulated and clearly explained. These additions improve the methodological clarity and strengthen the reliability of the optimisation analysis performed for MQL-assisted turning of Al 7075 alloy. In each trial, the character of each combination of process variables was retained and the related responses were subjected to statistical scrutiny to identify the most beneficial configuration of parameters. The ability of grey relational analysis to condense a collection of responses into a single relational grade makes it useful for multivariate analyses.

Data normalisation is the first of three sequential steps, which are followed by the calculation of grey relational coefficients and, lastly, the determination of grey relational grades. The following shows how normalisation is carried out for a criterion, such as cutting temperature, where a lower value denotes better performance [33,34]:

$$X'_i = \frac{\max(x) - x_i}{\max(x) - \min(x)}. \quad (1)$$

The normalisation process is defined by the following when working with parameters such as material removal rate and tool life, where higher values indicate better results:

$$X'_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}. \quad (2)$$

The deviation sequence is calculated as follows to assess how closely each normalised value resembles the ideal benchmark:

$$\Delta_i = |X_0 - X'_i|, \quad (3)$$

where $X_0 = 1$ is ideal.

The grey relational coefficient (GRC) was calculated using:

$$GRC_i = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_i + \zeta \Delta_{\max}}, \quad (4)$$

where Δ_i is the deviation sequence, $\Delta_{\min}$ is the minimum deviation value, $\Delta_{\max}$ is the maximum deviation value and ζ is the distinguishing coefficient (taken as 0.5 in the present study).

Grey relational grade (GRG) was calculated using:

$$GRG = \frac{1}{n} \sum_{i=1}^n GRC_i, \quad (5)$$

where n is the number of criteria.

Equal weighting factors were assigned to cutting temperature, surface roughness, tool life and material removal rate during grey relational analysis to ensure unbiased multi-response optimisation of machining performance. This approach was adopted because all machining responses were considered equally significant for evaluating the combined effects of productivity, machining quality, thermal behaviour and tool durability under MQL-assisted turning conditions. The case with the highest GRG is considered optimal. This multi-criteria decision-making tool helps convert multiple performance metrics into a single comparable value [34]. Each machining condition was tested three times to confirm the consistency and repeatability of the experimental results obtained under different lubrication environments. The measured responses were expressed as mean values, with deviations within $\pm 3\%$ for cutting temperature, surface roughness and tool life measurements.

3. Results and discussion

3.1 Chip formation analysis

Figure 3 shows the chip morphology of Al 7075 alloy after dry, compressed air, waste cooking oil and vetiver oil machining. Under dry machining, the chip morphology is irregular and discontinuous, caused by high interfacial friction, high cutting temperature and an unstable plastic deformation process. When compressed air is used as a lubricant, it generates relatively fragmented chips because air cooling helps to remove the chips but does not provide sufficient boundary lubrication. As a result, waste cooking oil makes the chips curl and run in a continuous sequence, meaning less friction and better slip transferability at the tool-chip interface. Vetiver oil yields more uniform and smoother curled chips with more stable chip flow and better lubrication.

This agrees with the experimental machining results, in which vetiver oil yields lower cutting temperature and surface roughness and longer tool life. At the optimum condition of 745 rpm, 0.20 mm/rev and 0.50 mm depth of cut, vetiver oil induced a cutting temperature of 48 °C, a surface roughness of 0.802 μm and a tool life of 48 min,

while waste cooking oil induced a cutting temperature of 52 °C, a surface roughness of 1.02 μm and a tool life of 43 min. The chip morphology confirms the importance of lubrication in chip segmentation, flow and evacuation. Of the conditions examined, vetiver oil offers the most stable chip formation, resulting in better overall machining performance.

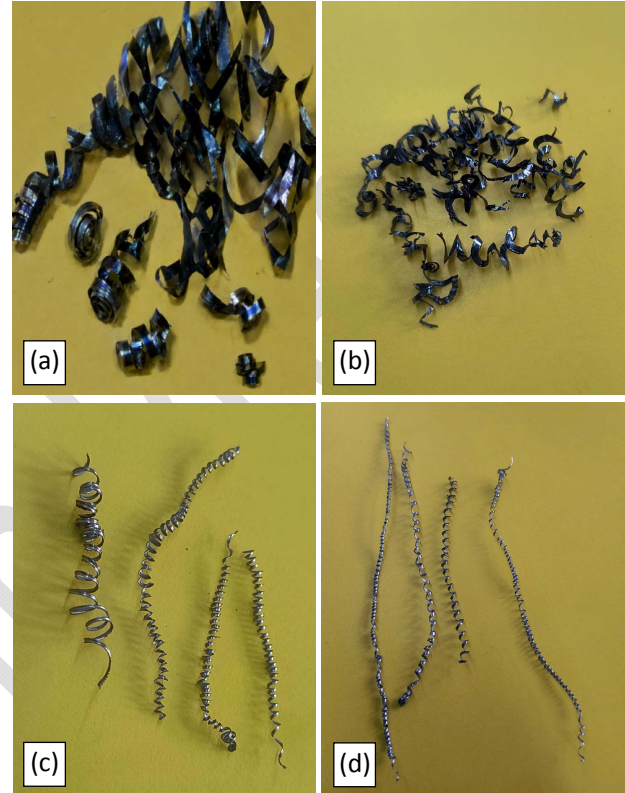


Figure 3. Chip formation under four different machining conditions: (a) dry, (b) compressed air, (c) waste cooking oil and (d) vetiver oil

3.2 Cutting temperature analysis

Figure 4 illustrates how cutting temperature varies with experimental parameters under different lubrication conditions, such as dry, compressed air, waste oil and vetiver oil machining. Table 3 shows the experimental results under dry machining, indicating higher cutting temperatures, increased surface roughness and reduced tool life. Cutting temperature values show predictable trends with respect to spindle speed, feed rate, depth of cut and lubrication condition. In all experiments, the highest temperature was recorded under dry machining, followed by compressed air, waste cooking oil and vetiver oil, which recorded the lowest temperature. This is consistent with MQL machining results, where bio-based oils produce lower frictional heat at the tool-chip interface due to their superior lubricity [6,8].

Table 3. Experimental results for dry machining of Al 7075

Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min
745	0.2	0.50	68	1.564	33	20
745	0.3	0.75	74	1.626	27	32
745	0.4	1.00	80	1.832	24	45
745	0.5	1.25	87	1.945	17	56
1305	0.2	0.50	73	1.585	25	35
1305	0.3	0.75	78	1.722	22	52
1305	0.4	1.00	87	1.943	18	70
1305	0.5	1.25	92	2.186	15	90
1850	0.2	0.50	72	1.722	21	50
1850	0.3	0.75	81	1.824	18	74
1850	0.4	1.00	90	2.052	14	100
1850	0.5	1.25	98	2.224	12	128
2530	0.2	0.50	85	1.852	17	68
2530	0.3	0.75	90	1.967	13	99
2530	0.4	1.00	99	2.385	10	135
2530	0.5	1.25	110	2.342	8	171

Table 4. Experimental results for compressed air machining of Al 7075

Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min
745	0.2	0.50	60	1.440	36	21
745	0.3	0.75	68	1.460	33	33
745	0.4	1.00	72	1.630	28	46
745	0.5	1.25	78	1.820	23	57
1305	0.2	0.50	67	1.500	30	36
1305	0.3	0.75	71	1.620	26	53
1305	0.4	1.00	79	1.800	22	71
1305	0.5	1.25	86	1.990	19	91
1850	0.2	0.50	65	1.620	26	51
1850	0.3	0.75	77	1.720	23	75
1850	0.4	1.00	84	1.940	19	102
1850	0.5	1.25	93	2.015	16	130
2530	0.2	0.50	80	1.750	20	69
2530	0.3	0.75	84	1.850	17	100
2530	0.4	1.00	92	2.210	13	137
2530	0.5	1.25	102	2.120	11	173

Table 4 presents the results for compressed air machining, showing moderate improvement in machining performance compared with dry

machining. Increasing spindle speed and material removal rate raised temperatures, which is consistent with traditional machining theory,

where higher cutting speeds increase plastic deformation and frictional heat. For instance, at 2530 rpm, dry machining cutting temperature was 110 °C, while the vetiver oil kept temperatures at 76 °C. Srikant and Rao [8] reported similar temperature reductions of 5 to 12 % with vegetable-based oils, confirming the good performance of biolubricants in temperature control. The better performance of vetiver oil than waste cooking oil can be explained by its higher viscosity and thermal conductivity, which help dissipate heat and sustain a protective lubricant film at high temperatures.

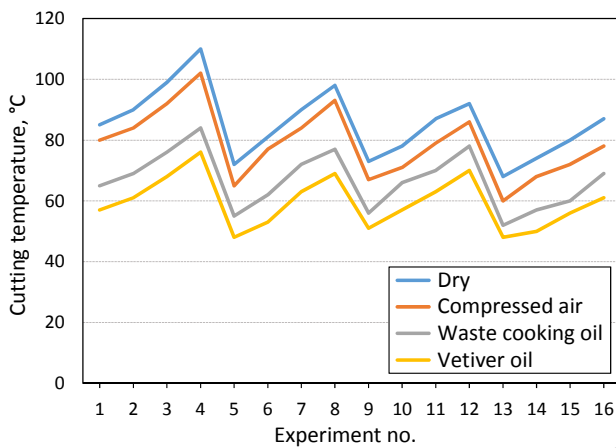


Figure 4. Cutting temperature variation with experimental conditions

These findings align with tribological principles, i.e. under dry conditions, high tool-chip contact increases friction and heat generation. Compressed air offers minimal heat removal (convective cooling) and chip evacuation, with only minor temperature reduction. On the other hand, waste cooking oil and vetiver oil provide boundary lubrication, reducing shear stress and friction. Similarly, Kouam et al. [4] and Kuram et al. [6] found that vegetable oils form a protective layer that lowers cutting temperature and increases thermal stability. While film strength may decrease at higher cutting speeds, the oils' effectiveness suggests they are not easily removed or broken down.

3.3 Surface roughness analysis

Figure 5 shows the variation in surface roughness (R_a) under different lubrication conditions, illustrating how lubrication affects machined surface quality during the turning of Al 7075. The surface topography for four machining conditions shows clear differences in roughness, as shown in Figure 6, which align with the measured R_a values. The obtained results show that the lubrication environment strongly influenced surface integrity and machining performance, with bio-based lubricants producing a better surface roughness than dry machining.

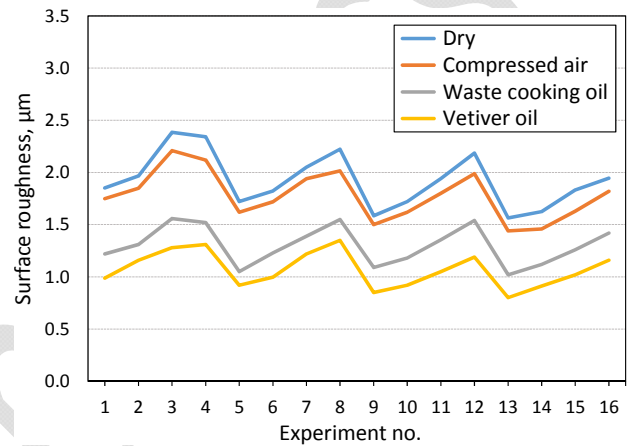


Figure 5. Surface roughness variation with experimental conditions

Dry machining shows the highest roughness, with R_a values exceeding 2.3 µm, due to high friction, thermal softening and built-up edge formation, reflecting the negative impacts of adhesion and unstable chip formation. Compressed air machining induced a more uniform texture with reduced asperity height, indicating some benefits from cooling and chip removal despite ongoing friction-induced wear. Waste cooking oil machining resulted in moderate roughness with lower peak intensity, attributed to lubrication that minimises tool-chip contact and stabilises the cutting process. Vetiver oil machining produced the smoothest surface, characterised by aligned features and minimal height variation, indicating effective

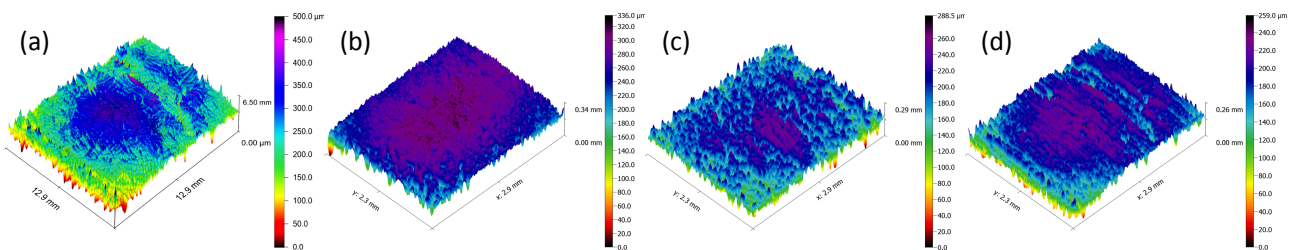


Figure 6. Surface topography under four different machining conditions: (a) dry, (b) compressed air, (c) waste cooking oil and (d) vetiver oil

lubrication, efficient heat dissipation and stable machining conditions. This progression from dry to vetiver oil machining underscores how improved lubrication and cooling can significantly enhance both surface roughness and overall machining performance. Wickramasinghe et al. [7] and Gunjal et al. [13] reported similar benefits from vegetable oils, showing the effectiveness of biolubricants in reducing friction and improving machining stability.

The best surface roughness ($Ra = 0.802 - 1.350 \mu\text{m}$) was obtained with vetiver oil, which shows superior lubrication behaviour. This is likely due to its ester structure, which facilitates good wetting and film formation. Similar conclusions have been made for vegetable oils, where polar functional groups improve lubrication and prevent built-up edge formation [14,21]. The stronger film helps to dampen vibration, improve cutting force stability and improve surface integrity. Feed rate had the strongest impact on roughness due to geometry, and depth of cut affected roughness due to increased cutting forces. Spindle speed had a dual effect: it improved surface integrity under lubrication due to enhanced chip transport, but increased surface roughness under dry machining due to thermal instability. The improved machining response obtained with vetiver oil lubrication may be associated with the formation of a thin protective lubricating layer between the cutting tool and the flowing chip, reducing interfacial friction, thermal accumulation and surface damage during MQL turning of Al 7075. Additional studies on surface interaction analysis and microscopic wear characterisation are needed to better understand the lubrication mechanism and durability of the bio-based fluid under prolonged machining.

In summary, the findings confirm that lubrication quality is the most important factor in determining surface integrity. Vetiver oil machining obtained the best results due to excellent boundary lubrication and thermal stability, which is in agreement with recent research on biodegradable cutting fluid-assisted machining [23].

3.4 Material removal rate and tool life analysis

Figures 7 and 8 depict variations in material removal rate and tool life under different lubrication conditions, emphasising the role of lubrication in enhancing tool performance and durability. Table 5 presents the outcomes for using waste cooking oil, revealing a better surface roughness and relatively improved tool life. The

material removal rate and tool life data show that cutting parameters and lubrication conditions affect machining efficiency differently. The material removal rate showed a clear dependence on spindle speed, feed rate, and depth of cut, but negligible changes with different lubrication conditions (dry, compressed air, waste cooking oil and vetiver oil machining). This finding aligns with the theoretical predictability that material removal rate is directly related to spindle speed, feed rate and depth of cut [24]. At the peak spindle speed of 2530 rpm, the material removal rate spanned a range of $68 - 178 \text{ mm}^3/\text{s}$, with near-linear growth with feed rate and depth of cut. Reducing the spindle speed (e.g. to 745 rpm) resulted in a proportional reduction in material removal rate, verifying that kinematic parameters play a major role. The slight increases in material removal rate with lubrication (especially vetiver oil) were due to better chip evacuation and reduced friction force, which helped stabilise the cutting process without significant volume commitments, as Kouam et al. [4] similarly noted.

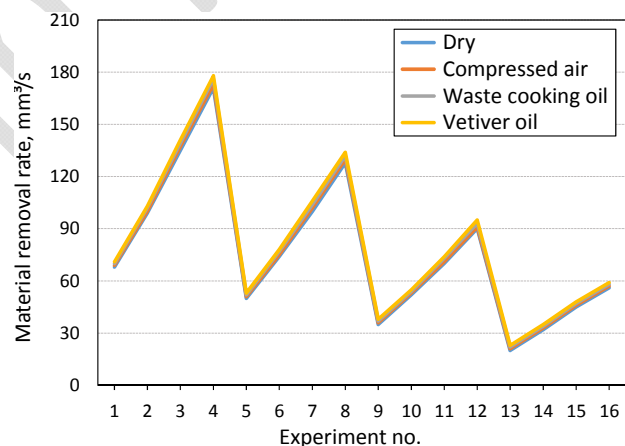


Figure 7. Material removal rate variation with experimental conditions

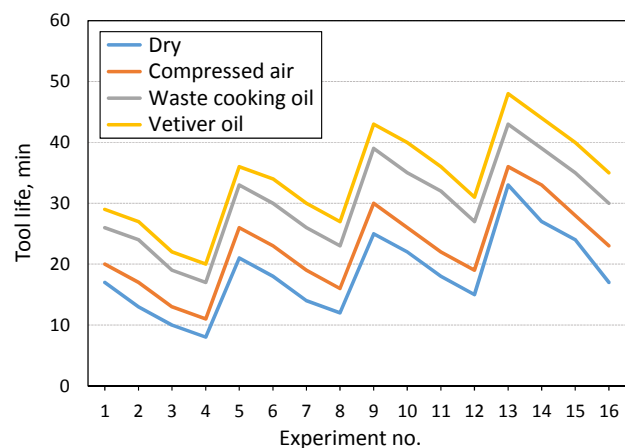


Figure 8. Tool life variation with experimental conditions

Table 5. Experimental results for waste cooking oil machining of Al 7075

Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min
745	0.2	0.50	52	1.020	43	22
745	0.3	0.75	57	1.120	39	34
745	0.4	1.00	60	1.260	35	47
745	0.5	1.25	69	1.420	30	58
1305	0.2	0.50	56	1.090	39	37
1305	0.3	0.75	66	1.180	35	54
1305	0.4	1.00	70	1.356	32	73
1305	0.5	1.25	78	1.540	27	93
1850	0.2	0.50	55	1.050	33	52
1850	0.3	0.75	62	1.230	30	77
1850	0.4	1.00	72	1.390	26	104
1850	0.5	1.25	77	1.550	23	132
2530	0.2	0.50	65	1.220	26	70
2530	0.3	0.75	69	1.310	24	102
2530	0.4	1.00	76	1.560	19	139
2530	0.5	1.25	84	1.520	17	176

Table 6. Experimental results for vetiver oil machining of Al 7075

Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min
745	0.2	0.50	48	0.802	48	23
745	0.3	0.75	50	0.912	44	35
745	0.4	1.00	56	1.020	40	48
745	0.5	1.25	61	1.160	35	59
1305	0.2	0.50	51	0.850	43	38
1305	0.3	0.75	57	0.920	40	55
1305	0.4	1.00	63	1.050	36	74
1305	0.5	1.25	70	1.190	31	95
1850	0.2	0.50	48	0.920	36	53
1850	0.3	0.75	53	0.998	34	78
1850	0.4	1.00	63	1.220	30	106
1850	0.5	1.25	69	1.350	27	134
2530	0.2	0.50	57	0.988	29	71
2530	0.3	0.75	61	1.160	27	103
2530	0.4	1.00	68	1.280	22	141
2530	0.5	1.25	76	1.310	20	178

Tool wear during turning of Al 7075 was mainly characterised by abrasive flank wear, adhesive material deposition and thermally

induced edge deterioration developed under elevated cutting conditions. Using vetiver oil and waste cooking oil under MQL machining reduced

overall tool wear by minimising frictional contact and controlling heat accumulation at the tool-chip interface. The superior performance under vetiver oil lubrication may be due to vetiver oil's relatively high flash point and appropriate viscosity. These properties help form a stable lubricating film between the tool and the chip, reducing adhesive contact and frictional heat generation. Therefore, tool wear and surface integrity were improved compared with dry and compressed air machining.

Table 6 presents the results for vetiver oil machining, showing a significant reduction in surface roughness and enhanced tool life. Conversely, cutting and lubrication parameters strongly influenced tool life. Overall, dry machining produced the shortest tool life, followed by compressed air, waste cooking oil and vetiver oil machining. This result supports previous findings that vegetable oils increase tool life by reducing friction, heat and wear [8]. As spindle speed increased, tool life decreased, agreeing with Taylor's tool-life theory, since higher speed raises cutting temperature and increases wear rate through mechanisms such as adhesion and abrasion. For instance, lowering the spindle speed from 2530 to 745 rpm almost doubled tool life in all cases. Moreover, tool life decreased with higher feed rates and depths of cut, in accordance with previous findings, which demonstrate that larger chip loads increase heat and tool wear [14,15]. In summary, while material removal rate is largely determined by machining parameters, tool life depends significantly on the quality of lubrication, with vetiver oil leading in reducing tool wear and extending tool life.

3.5 Grey relational analysis

The grey relational analysis method was used to determine overall machining performance by calculating the grey relational grade (GRG) of cutting temperature, surface roughness, material removal rate and tool life. This method considers multiple machining responses, which is necessary when improvements in one machining parameter adversely affect other responses [34].

Tables 7 and 8 summarise the grey relational grades and rankings, identifying the optimal machining parameters based on overall performance. For waste cooking oil, the GRG ranged from 0.484 to 0.833, confirming that cutting parameters significantly affect GRG. The highest GRG (0.833) was achieved at a spindle

speed of 745 rpm, a feed rate of 0.20 mm/rev and a depth of cut of 0.50 mm. These conditions provided the highest reduction in cutting temperature (52 °C), the best surface roughness (1.020 μm) and the longest tool life (43 min), but resulted in a comparatively low material removal rate (22 mm^3/min). This suggests that lower cutting severity improves lubrication and reduces cutting forces and temperatures. GRG values declined gradually as feed rate and depth of cut increased because of higher heat generation, poorer surface quality and higher tool wear, while material removal rate increased. These trends have also been noticed in other multi-objective machining optimisation studies [13].

The trend for the vetiver oil was similar, but the GRG values were significantly higher (0.443 – 0.833). The optimal condition was the same as for waste cooking oil but with better responses, such as reduced cutting temperature (48 °C), improved surface roughness (0.802 μm) and increased tool life (48 min). This improvement can be explained by better lubrication performance, as bio-based oils reduce friction and wear at the cutting edge [8,14]. Some studies reported that these lubricants also help maintain thermal stability and machining stability under different cutting conditions [21].

The investigation generally confirms that feed rate and depth of cut are the most important machining parameters, while spindle speed has minimal impact. Although higher machining parameters increase material removal rate, their detrimental effects on temperature, surface roughness and tool life reduce overall performance. Of the cutting fluids, vetiver oil consistently provided improved machining performance and stability, confirming its potential as an effective and eco-friendly cutting fluid for machining of Al 7075.

The grey relational grade results were verified by comparing them with results obtained during machining. The parameter setting of 745 rpm spindle speed, 0.20 mm/rev feed rate and 0.50 mm depth of cut obtained the best combined machining performance under both waste cooking oil and vetiver oil machining conditions.

Higher GRG values corresponded to lower cutting temperatures, improved surface roughness and longer tool lives, confirming the consistency of the optimisation results. The close match between the optimised parameters and the experimental outcomes demonstrates that grey relational

analysis is suitable for multi-response optimisation of Al 7075 machining. Additionally, grey relational analysis was preferred over TOPSIS, PCA and desirability analysis due to its simpler

computation, lower sensitivity to weighting and normalisation effects and more direct conversion of multiple responses into a single performance index for reliable decision-making.

Table 7. Grey relational grades (GRG) and rankings for waste cooking oil machining of Al 7075

Rank	Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min	GRG
1	745	0.2	0.50	52	1.020	43	22	0.833
2	1305	0.2	0.50	56	1.090	39	37	0.728
3	745	0.3	0.75	57	1.120	39	34	0.713
4	1850	0.2	0.50	55	1.050	33	52	0.654
5	1305	0.3	0.75	66	1.180	35	54	0.647
6	745	0.4	1.00	60	1.260	35	47	0.601
7	1850	0.3	0.75	62	1.230	30	77	0.601
8	2530	0.2	0.50	65	1.220	26	70	0.580
9	1305	0.4	1.00	70	1.356	32	73	0.569
10	2530	0.5	1.25	84	1.520	17	176	0.549
11	745	0.5	1.25	69	1.420	30	58	0.546
12	2530	0.3	0.75	69	1.310	24	102	0.538
13	1305	0.5	1.25	78	1.540	27	93	0.516
14	1850	0.4	1.00	72	1.390	26	104	0.511
15	1850	0.5	1.25	77	1.550	23	132	0.490
16	2530	0.4	1.00	76	1.560	19	139	0.484

Table 8. Grey relational grades (GRG) and rankings for vetiver oil machining of Al 7075

Rank	Spindle speed, rpm	Feed rate, mm/ rev	Depth of cut, mm	Cutting temperature, °C	Surface roughness, μm	Tool life, min	Material removal rate, mm^3/min	GRG
1	745	0.2	0.50	48	0.802	48	23	0.833
2	1305	0.2	0.50	51	0.850	43	38	0.692
3	745	0.3	0.75	50	0.912	44	35	0.679
4	1850	0.2	0.50	48	0.920	36	53	0.655
5	745	0.4	1.00	56	1.020	40	48	0.586
6	1305	0.3	0.75	57	0.920	40	55	0.583
7	1850	0.3	0.75	53	0.998	34	78	0.564
8	2530	0.2	0.50	57	0.988	29	71	0.512
9	745	0.5	1.25	61	1.160	35	59	0.507
10	2530	0.5	1.25	76	1.310	20	178	0.504
11	1305	0.4	1.00	63	1.050	36	74	0.502
12	1305	0.5	1.25	70	1.190	31	95	0.481
13	2530	0.3	0.75	61	1.160	27	103	0.465
14	1850	0.4	1.00	63	1.220	30	106	0.459
15	2530	0.4	1.00	68	1.280	22	141	0.451
16	1850	0.5	1.25	69	1.350	27	134	0.443

4. Conclusions

The present investigation evaluated the performance of dry machining, compressed air machining, waste cooking oil machining and vetiver oil machining of aluminium alloy Al 7075 under a minimum quantity lubrication environment.

The experimental results confirmed that the lubrication environment plays a major role in controlling machining temperature, surface integrity and cutting tool durability. Among the tested conditions, vetiver oil machining showed the most stable machining behaviour due to its superior lubricating and heat-dissipation capability, resulting in lower cutting temperature, improved surface roughness and extended tool life. Waste cooking oil also showed noticeable improvement over dry and compressed air machining, indicating its suitability as an economical and environmentally sustainable cutting-fluid alternative.

The material removal rate was primarily governed by spindle speed, feed rate and depth of cut rather than lubrication condition, confirming that machining productivity mainly depends on cutting parameters. Dry machining generated severe thermal effects, rapid tool degradation and poor surface characteristics because of increased friction and unstable chip-tool interaction. Compressed air machining provided limited cooling assistance, but did not significantly reduce frictional effects during machining.

Grey relational analysis identified the optimal machining combination for balanced performance under MQL with biolubricants. The results demonstrate that biodegradable lubricants can effectively enhance machining efficiency while reducing the environmental impact associated with conventional mineral-based cutting fluids. Although the present study focused only on Al 7075 alloy and selected machining conditions, it provides a useful foundation for future investigations into hybrid biolubricants for manufacturing applications.

The present study is limited to Al 7075 alloy and a fixed range of machining parameters, which may restrict the generalisation of the results to other materials and cutting conditions. The study mainly focuses on lubrication effects and does not include detailed microscopic or wear mechanism analysis of tool-chip interaction. Further investigation involving different workpiece materials, tool coatings and extended wear studies is needed to broaden the applicability of the findings.

Acknowledgement

We would like to express our sincere gratitude to our supervisor, Dr. P. Kalidoss, Assistant Professor, Department of Mechanical Engineering, Dhanalakshmi Srinivasan University, Trichy, for his invaluable guidance, extensive knowledge, continuous encouragement and unwavering support throughout this research work.

References

- [1] H.J. Pei, W.J. Zheng, G.C. Wang, H.Q. Wang, Application of biodegradable cutting fluids in high speed turning, *Advanced Materials Research*, Vol. 381, 2011, pp. 20-24, DOI: [10.4028/www.scientific.net/AMR.381.20](https://doi.org/10.4028/www.scientific.net/AMR.381.20)
- [2] E. Kilickap, M. Huseyinoglu, C. Ozel, Empirical study regarding the effects of minimum quantity lubricant utilization on performance characteristics in the drilling of Al 7075, *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol. 33, No. 1, 2011, pp. 52-57, DOI: [10.1590/S1678-58782011000100008](https://doi.org/10.1590/S1678-58782011000100008)
- [3] K.R. Adebayo, J. Tien-Chien, A.E. Titilayo, Influence of mango seed oil on surface roughness and cutting temperature during sustainable turning of AISI 1525 steel under minimum quantity lubrication environment, *E3S Web of Conferences*, Vol. 552, 2024, Paper 01073, DOI: [10.1051/e3sconf/202455201073](https://doi.org/10.1051/e3sconf/202455201073)
- [4] J. Kouam, V. Songmene, M. Balazinski, P. Hendrick, Effects of minimum quantity lubricating (MQL) conditions on machining of 7075-T6 aluminum alloy, *The International Journal of Advanced Manufacturing Technology*, Vol. 79, No. 5-8, 2015, pp. 1325-1334, DOI: [10.1007/s00170-015-6940-6](https://doi.org/10.1007/s00170-015-6940-6)
- [5] C.A. Schuch Bork, J.F. Souza Gonçalves, J.O. Gomes, The *Jatropha curcas* vegetable base soluble cutting oil as a renewable source in the machining of aluminum alloy 7050-T7451, *Industrial Lubrication and Tribology*, Vol. 67, No. 2, 2015, pp. 181-195, DOI: [10.1108/ILT-09-2014-0090](https://doi.org/10.1108/ILT-09-2014-0090)
- [6] E. Kuram, B. Ozcelik, E. Demirbas, Environmentally friendly machining: Vegetable based cutting fluids, in J.P. Davim (Ed.), *Green Manufacturing Processes and Systems*, Springer, Berlin, 2013, pp. 23-47, DOI: [10.1007/978-3-642-33792-5_2](https://doi.org/10.1007/978-3-642-33792-5_2)
- [7] K.C. Wickramasinghe, G.I.P. Perera, H.M.C.M. Herath, Formulation and performance evaluation of a novel coconut oil-based metalworking fluid, *Materials and Manufacturing Processes*, Vol. 32, No. 9, 2017,

- pp. 1026-1033, DOI: [10.1080/10426914.2016.1257858](https://doi.org/10.1080/10426914.2016.1257858)
- [8] R.R. Srikant, P.N. Rao, Use of vegetable-based cutting fluids for sustainable machining, in J.P. Davim (Ed.), *Sustainable Machining*, Springer, Cham, 2017, pp. 31-46, DOI: [10.1007/978-3-319-51961-6_2](https://doi.org/10.1007/978-3-319-51961-6_2)
- [9] N. Rosli, N.E.H. Zamiruddin, Application of minimum quantity lubrication for various machining processes – A mini review, *Journal of Modern Manufacturing Systems and Technology*, Vol. 4, No. 2, 2020, pp. 40-47, DOI: [10.15282/jmmst.v4i2.5137](https://doi.org/10.15282/jmmst.v4i2.5137)
- [10] P. Kalidoss, S. Venkatachalapathy, S. Suresh, Optical and thermal properties of Therminol 55-TiO₂ nanofluids for solar energy storage, *International Journal of Photoenergy*, Vol. 2020, 2020, Paper 7085497, DOI: [10.1155/2020/7085497](https://doi.org/10.1155/2020/7085497)
- [11] P. Kalidoss, S.G. Venkatachalapathy, S. Suresh, Photothermal performance of hybrid nanofluids with different base fluids for solar energy applications, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, Vol. 47, No. 1, 2025, pp. 8688-8703, DOI: [10.1080/15567036.2021.1936697](https://doi.org/10.1080/15567036.2021.1936697)
- [12] A.A. Chavan, V.G. Sargade, Statistical and multi-attribute analysis in hardened steel turning under vegetable oil-based MQL, in P.M. Pawar, R. Balasubramaniam, B.P. Ronge, S.B. Salunkhe, A.S. Vibhute, B. Melinamath (Eds.), *Techno-Societal 2020*, Springer, Cham, 2021, pp. 777-789, DOI: [10.1007/978-3-030-69925-3_75](https://doi.org/10.1007/978-3-030-69925-3_75)
- [13] S.U. Gunjal, S.B. Sanap, L. Jadhav, N.G. Patil, Role of bio-cutting fluids under minimum quantity lubrication: An experimental investigation of a sustainable machining technique, in R.K. Phanden, K. Mathiyazhagan, R. Kumar, J.P. Davim (Eds.), *Advances in Industrial and Production Engineering*, Springer, Singapore, 2021, pp. 707-719, DOI: [10.1007/978-981-33-4320-7_63](https://doi.org/10.1007/978-981-33-4320-7_63)
- [14] A. Alshibi, A. Nasreldin, S. Pervaiz, Sustainable vegetable oil-based minimum quantity lubrication assisted machining of AZ91 magnesium alloy: A grey relational analysis-based study, *Lubricants*, Vol. 11, No. 2, 2023, Paper 79, DOI: [10.3390/lubricants11020079](https://doi.org/10.3390/lubricants11020079)
- [15] A. Kumar, A.K. Sharma, J.K. Katiyar, State-of-the-art in sustainable machining of different materials using nano minimum quality lubrication (NMQL), *Lubricants*, Vol. 11, No. 2, 2023, Paper 64, DOI: [10.3390/lubricants11020064](https://doi.org/10.3390/lubricants11020064)
- [16] G. Basmacı, M.Y. Kayacan, M. Ay, A. Etyemez, Optimization of cutting forces and surface roughness via ANOVA and grey relational analysis in machining of In718, *Open Chemistry*, Vol. 21, 2023, Paper 20220273, DOI: [10.1515/chem-2022-0273](https://doi.org/10.1515/chem-2022-0273)
- [17] H.C. Pires Souza, A.S. Araújo Junior, F.J.R. Cangue, L.L. Thomé Vaughan, Environmentally friendly turning of AISI 316 stainless steel with vegetable oils under MQL, *The Journal of Engineering and Exact Sciences*, Vol. 11, 2025, Paper 22901, DOI: [10.18540/jcecvl11iss1pp22901](https://doi.org/10.18540/jcecvl11iss1pp22901)
- [18] L.I. Farfan-Cabrera, A. Rojo-Valerio, J.d.D. Calderon-Najera, K.G. Coronado-Apodaca, H.M.N. Iqbal, R. Parra-Saldivar, M. Franco-Morgado, A. Elias-Zuñiga, Microalgae oil-based metal working fluids for sustainable minimum quantity lubrication (MQL) operations – A perspective, *Lubricants*, Vol. 11, No. 5, 2023, Paper 215, DOI: [10.3390/lubricants11050215](https://doi.org/10.3390/lubricants11050215)
- [19] R.M. Parthe, Minimum quantity lubrication – An emerging technology for sustainable development, *International Journal of Scientific Research in Engineering and Management*, Vol. 7, No. 6, 2023, Paper IJSREM24019, DOI: [10.55041/ijserem24019](https://doi.org/10.55041/ijserem24019)
- [20] B. Sen, S.K. Kothapalli, R. Kumar, C. Manjunath, I. Abdullah, G. Singh, A. Johnson Santhosh, Minimum quantity blended bio-lubricants for sustainable machining of superalloy: An MCDM model-based study, *AIP Advances*, Vol. 14, No. 7, 2024, Paper 075224, DOI: [10.1063/5.0222561](https://doi.org/10.1063/5.0222561)
- [21] M.A. Makhesana, K.M. Patel, N.D. Ghetiya, R. Binali, M. Kuntoğlu, Evaluation of drilling and hole quality characteristics in green machining aluminium alloys: A new approach towards green machining, *Journal of Manufacturing Processes*, Vol. 129, 2024, pp. 176-186, DOI: [10.1016/j.jmapro.2024.08.059](https://doi.org/10.1016/j.jmapro.2024.08.059)
- [22] R.S. Situmorang, A.A.C. Saragih, C.P.A. Hutaaruk, J. Haryanto, W. Simanullang, A. Irwan, H.V. Sihombing, W.F. Simanullang, Y. Oishi, Synthesis and characterisation of palm oil-based biolubricant for application as cutting fluid, *Tribology and Materials*, Vol. 4, No. 4, 2025, pp. 192-200, DOI: [10.46793/tribomat.2025.018](https://doi.org/10.46793/tribomat.2025.018)
- [23] G. Rajasozhaperumal, C. Kannan, Towards sustainable machining: An experimental study of eco-friendly MQL and its impact on machinability and future opportunities, *Engineering Research Express*, Vol. 6, No. 4, 2024, Paper 045574, DOI: [10.1088/2631-8695/ad9889](https://doi.org/10.1088/2631-8695/ad9889)
- [24] R.A. Kazeem, I.O. Enobun, I.G. Akande, T.-C. Jen, S.A. Akinlabi, O.M. Ikumapayi, E.T. Akinlabi, Evaluation of palm kernel oil as lubricants in cylindrical turning of AISI 304 austenitic stainless steel using Taguchi-grey relational methodology,

- Materials Research Express, Vol. 10, No. 12, 2023, Paper 126505, DOI: [10.1088/2053-1591/ad11fe](https://doi.org/10.1088/2053-1591/ad11fe)
- [25] A. Kannan, N.M. Sivaram, Evaluation and performance improvement of environmentally friendly sustainable turning of 6063 aluminum alloy in dry conditions using grey relational analysis, International Journal of Automotive and Mechanical Engineering, Vol. 21, No. 1, 2024, pp. 11085-11098, DOI: [10.15282/ijame.21.1.2024.12.0858](https://doi.org/10.15282/ijame.21.1.2024.12.0858)
- [26] R.A. Kazeem, D.A. Fadare, I.G. Akande, T.-C. Jen, S.A. Akinlabi, E.T. Akinlabi, Evaluation of crude watermelon oil as lubricant in cylindrical turning of AISI 1525 steel employing Taguchi and grey relational analyses techniques, Heliyon, Vol. 10, No. 3, 2024, Paper e25349, DOI: [10.1016/j.heliyon.2024.e25349](https://doi.org/10.1016/j.heliyon.2024.e25349)
- [27] M. Karthikraja, P. Kalidoss, S. Anbu, P. Prabakaran, Enhanced cooling techniques for Inconel 718 drilling using nano-ionic liquid coolants, Latin American Applied Research, Vol. 55, No. 3, 2025, pp. 333-339, DOI: [10.52292/j.laar.2025.3559](https://doi.org/10.52292/j.laar.2025.3559)
- [28] F.N. Al Zubaidi, L.M. Asaad, I. Alshalal, M. Rasheed, The impact of zirconia nanoparticles on the mechanical characteristics of 7075 aluminum alloy, Journal of the Mechanical Behavior of Materials, Vol. 32, No. 1, 2023, Paper 20220302, DOI: [10.1515/jmbm-2022-0302](https://doi.org/10.1515/jmbm-2022-0302)
- [29] O. Awogbemi, D.V.V. Kallon, V.S. Aigbodion, S. Panda, Advances in biotechnological applications of waste cooking oil, Case Studies in Chemical and Environmental Engineering, Vol. 4, 2021, Paper 100158, DOI: [10.1016/j.cscee.2021.100158](https://doi.org/10.1016/j.cscee.2021.100158)
- [30] E. Yanto, E. Agustian, A. Sulaswatty, Simple purification of vetiver oil by multiglass plate system for quality improvement, Jurnal Kimia Terapan Indonesia, Vol. 18, No. 2, 2016, pp. 124-131.
- [31] M.D. Mijailović, V.M. Tadić, I.B. Krstić, J.M. Avramović, A.V. Veličković, A.T. Zahitović, V.B. Veljković, M.S. Krstić, Kinetics of the essential oil hydrodistillation from sweet flag (*Acorus calamus*) rhizomes: Comparison of basic models, Journal of Chemical Technology and Biotechnology, Vol. 101, No. 1, 2026, pp. 144-153, DOI: [10.1002/jctb.70076](https://doi.org/10.1002/jctb.70076)
- [32] S.I. Lamido, B.A. Abba, M. Ibrahim, Essential oil extraction from lemongrass using steam and hydro distillation from a locally fabricated extractor, Global Journal of Engineering and Technology Advances, Vol. 21, No. 1, 2024, pp. 190-196, DOI: [10.30574/gjeta.2024.21.1.0198](https://doi.org/10.30574/gjeta.2024.21.1.0198)
- [33] N. Nagesha, B.S. Praveen Kumar, Optimizing turning parameters using Taguchi method to maximize tool life and minimize wear and vibration, Journal of Mines, Metals and Fuels, Vol. 73, No. 1, 2025, pp. 75-86, DOI: [10.18311/jmmf/2025/47072](https://doi.org/10.18311/jmmf/2025/47072)
- [34] L. Yang, Y. Jiang, Y. Yang, G. Zeng, Z. Zhu, J. Chen, Classification-based parameter optimization approach of the turning process, Machines, Vol. 12, No. 11, 2024, Paper 805, DOI: [10.3390/machines12110805](https://doi.org/10.3390/machines12110805)