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Performance Investigation of Graphene Based-Nanofluids as A Metalworking Fluid for Turning Process

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Abstract. Most lubricants used for machining industry are mineral-based oil thus gives negative impact on environment and humans because of their toxicity and non-biodegradability. Therefore, vegetable-based oil has been taken as other initiatives to produce bio-based metalworking fluid (MWFs) especially from non-edible oil (jatropha oil). The aim of this study was to investigate the turning performance of nanofluids from modified jatropha based-oil (MJO) with the addition of graphene nanoparticles at various concentrations (0.01wt%, 0.025wt%, 0.05wt%). The performances of MJO based nanofluids were compared with synthetic ester (SE) as the benchmark oil in terms of cutting temperature, chip thickness and workpiece surface roughness. From the results, MJO + 0.025wt% graphene nanoparticles recorded the lowest cutting temperature, and chip thickness with smoother workpiece surface roughness compared to all samples. In conclusion, MJO + 0.025wt% exhibit superior machining performance and could be potential candidate as sustainable MWFs to replace mineral based oil for the machining processes.

INTRODUCTION

Machining is one of the most fundamental and indispensable processes in manufacturing industry. Due to the friction between the tool and the workpiece, it experiences high temperatures in the machining process, thus influencing dimensional accuracy and surface quality of the workpiece. However, temperatures for machining can be reduced by metalworking fluids (MWFs). MWFs are the best option in the machining phase, which serves as a cooling and lubricating agent at the cutting zone, thus improve the machining productivity and quality [1]. The main sources of these fluids are from mineral oil-based, vegetable oil-based and synthetic oils. But lately vegetable oil based MWF's are being used because of its eco-friendly nature compared to mineral based oils. Vegetable oil have been chooses because it exhibited higher lubricity, lower volatility, higher viscosity index and flash point than mineral and synthetic oil. However, vegetable oils are out performed because of their low thermal properties and presence of double bonds in the carbon chain of fatty acids for vegetable oils causing high wear rate [2].

Moreover, the addition of nanoparticles which are graphene nanoparticles to vegetable-based oils gives the optimum performance for lubricants by reducing the friction between cutting tool and workpiece. Graphene nanoparticles has an extremely smooth surface, chemical inertness, and easy shear ability within the layers of its stack which is the extreme properties of graphene that have potential to reduce friction [3]. Combination of vegetable based-oil with nanoparticles as a nanofluids, applied in the form of minimum quantity lubrication (MQL) method will provide major environmental benefits without sacrificing the machining performance. MQL improved surface finish, reduced tool wear and dimensional deviations [4]. Nanofluids are produced by adding nanoparticles in modified jatropha oil to provide superior thermal and friction reduction qualities in machining process. Besides, Liu et al. [5] found that the friction was reduced by nanoparticles scatter to form class bearings and convert sliding

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friction into rolling friction, thereby reducing the friction coefficient and showing excellent anti-friction performance. Therefore, the aim of this study is to investigate the performance of the modified jatropha oil with the addition of graphene nanoparticles through the turning process.

METHODOLOGY

In this study, the crude jatropha oil (CJO) was undergo the chemical alteration through two step acid-based catalyst to obtain the jatropha methyl ester (JME) [6]. Next, a chemical reaction between JME with trimethylolpropane (TMP) at a molar ratio of 3:5:1 and the presence of 1% (wt./wt.) of sodium methoxide (NaOCH3) for the formation of TMP triesters or as modified jatropha oil (MJO) was involved. Table 1 shows the physicochemical properties of MJO. Further, MJO was mixed with graphene nanoparticle additives at various concentrations (0.01wt%, 0.025wt%, 0.05wt%) to formulate the nanofluids. For the nanofluids mixing process, MJO was blended with graphene nanoparticles at temperature of 60°C and 700 rpm using magnetic stirrer for 30 minutes. Table 2 shows the properties of graphene nanoparticle. The MJO nanofluid samples was compared with Unicut Jinen MQL synthetic ester (SE) as the benchmark oil.

Table 1. Physicochemical properties of modified jatropha oil

Properties of MJO	Value
Density at 15 °C (g/cm^3)	0.9126
Kinematic viscosity at 40 °C (mm^2/s)	16.87
Kinematic viscosity at 100 °C (mm^2/s)	4.49
Viscosity index (VI)	196
Flash point (°C)	220.5
Acid value (mg NaOH/g)	0.34
Water content (% vol)	0.029

Table 2. Physical and mechanical properties of graphene [7]

Properties	Value
Charge carrier mobility	~200 000 cm^2 /V·s
Thermal conductivity	~5000 W/m·K
Specific surface area	~2630 m^2 /g
Young's modulus	~1 Tpa
Tensile strength	~1100 Gpa

Figure 1 shows the machining setup. The turning process was carried out on AISI 1045 using NC Harrison Alpha 400 under the following machining condition as shown in Table 3. AISI 1045 with diameter of 150mm and length of 200mm was used as workpiece to carry out the turning process. The metalworking fluids was supplied via MQL technique at the input pressure of 0.4 MPa with its flow rate at 0.16 l/hour. The nozzle was fixed inclined at 45° at 8mm from the cutting edge. The uncoated cermet inserts with 60° triangle shape (TNGG220408R) was mounted on the tool holder (MTQNR2525M22N). The turning process was performed at a cutting length of 100mm for each samples. The maximum cutting temperature was captured at the contact zone using FLIR T640 thermal imager camera. The average workpiece surface roughness value, R_a was measured using Mitutoyo Surface Roughness Tester (model SJ-400) according to ISO 4288:1996 standard. The surface roughness values was measured at four different places on the surface of workpiece. Besides, chip thickness also was measured using Mitutoyo IP65 tapered nose micrometer at 10 different samples of chips to take the average reading of each samples.

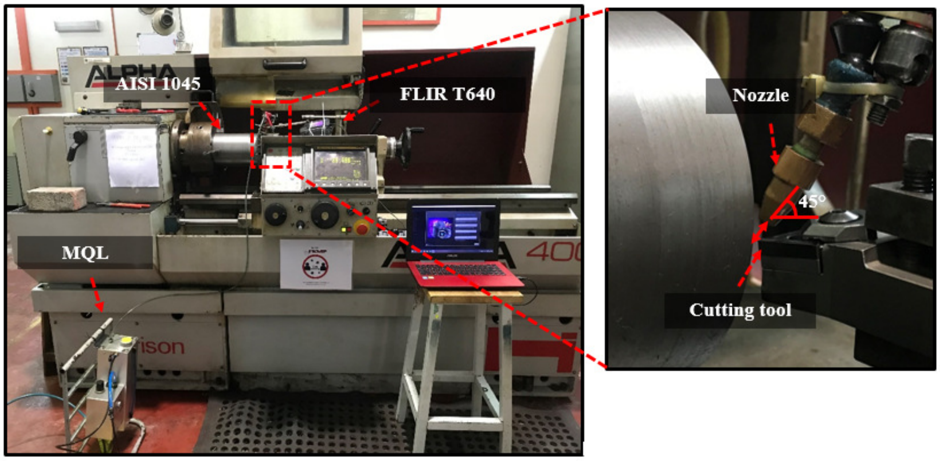

FIGURE 1. Turning process setup

TABLE 3. Machining condition

Description	Values
Cutting speed, *Vc* (m/min)	300
Feed rate, f_r (mm/rev)	0.2
Depth of cut (mm)	1
Oil flow rate (l/hour)	0.16
Workpiece material	AISI 1045
Cutting tool	Uncoated cermet
Type of lubricant	MJO + 0.01wt% Graphene MJO + 0.025wt% Graphene MJO + 0.05wt% Graphene
Benchmarking oil	Synthetic ester (SE)

RESULT AND DISCUSSION

Cutting Temperature

Figure 2 shows the result for the maximum cutting temperature for all samples of MWFs. SE was recorded as the second higher cutting temperature which is 198.8°C. However, from overall results shows that MJO samples with graphene nanoparticles recorded lower cutting temperature compared to SE. It could be observed that MJO + 0.05wt% graphene recorded the highest temperature with 23% increment higher than SE which is 257.7°C. This is because a higher concentration of graphene nanoparticles can cause some coagulation and promoting poor frictional properties during the machining process which can lead to increase of friction between contact surface of cutting tool and workpiece thus the cutting temperature was increased [6]. MJO + 0.01wt% have second higher cutting temperature that slightly lower by 25% compared to MJO + 0.05wt% concentration of graphene. In addition, MJO + 0.025% graphene record the lowest cutting temperature with 187.9°C compared to all other samples. This is because MJO + 0.025wt% graphene provides sufficient lubricating oil film that have good cooling capability thus reduce cutting temperature during machining process.

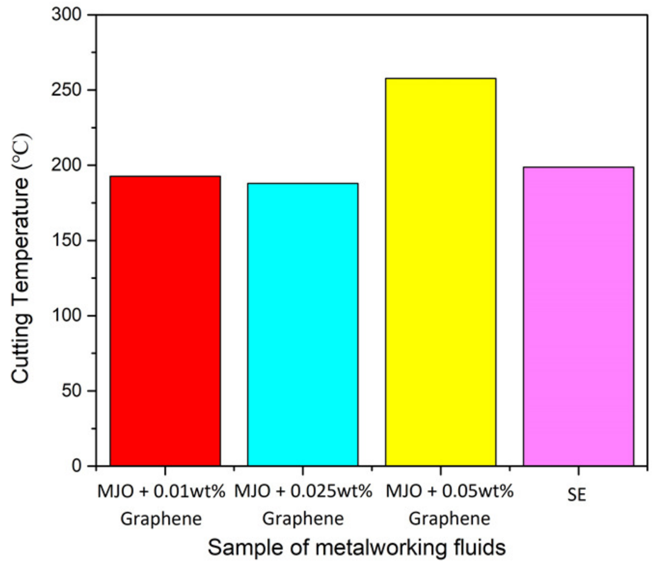

FIGURE 2. Graph of maximum cutting temperature

Workpiece surface roughness

Figure 3 illustrated the average workpiece surface roughness results for all samples. SE recorded the highest average surface roughness which is 2.86 µm compare to MJOs. This was proven that SE provided poor lubrication film as the worn surface produce was roughly comparing to MJO with the addition of graphene nanoparticles. MJO + 0.025wt% graphene records the lowest Ra which had a reduction of 32.17% compared to SE because of graphene nanoparticles can significantly reduce the friction and improve wear properties thus produce lower surface roughness. MJO + 0.01wt% graphene increased 1.03% compared to MJO + 0.025wt% graphene. The second highest in surface roughness was MJO + 0.05wt% graphene which is slightly lowest of 29.02% compared to SE. The low amount of graphene nanoparticles (0.01wt%) was considered not sufficient to strengthen the lubricating and cooling capabilities of oil film which could not helping for surface quality because of high friction contact during machining process. Besides, high concentration of graphene (0.05wt%) does not provide a smooth surface roughness because of the higher graphene concentration will adversely affect the lubricating capacity of suspension that attributed to phenomenon of nanoparticles aggregation resulting poor lubricity [8].

Chip thickness

Fig. 4 shows the average chip thickness for each sample of MWFs. From the Table 7, SE recorded the highest in terms of chip thickness compared to another sample of metalworking fluid. It can be seen that, MJO + 0.025wt% graphene was recorded as the lowest chip thickness among other MWFs. The reduction in chip thickness was recorded to be 34.5% lowest compared to SE. This is because the addition of graphene nanoparticles in MJOs could enhance its friction properties thus can reduce cutting temperature which can contribute to decreasing in chip thickness. Besides, MJO + 0.05wt% graphene was recorded slightly decreased by 19.35% compared to SE. Meanwhile, MJO + 0.01wt% graphene shows a slightly decreased of chip thickness compare to MJO + 0.05wt% graphene which is 0.8% compare to SE. High concentration of graphene (0.05wt%) produce thicker chip compare to others MJO sample with graphene additives because of coagulation of nanoparticles that attributed to poor frictional properties thus increase the cutting temperature [6].

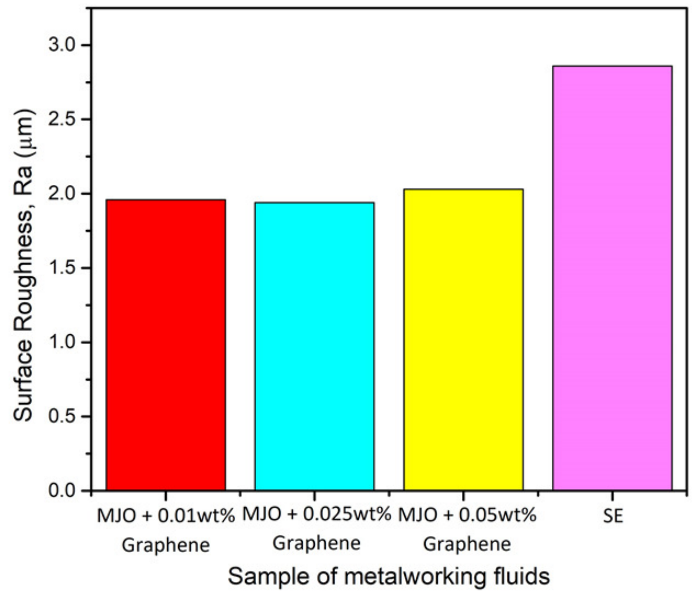

FIGURE 3. Graph of surface roughness of the workpiece for each sample

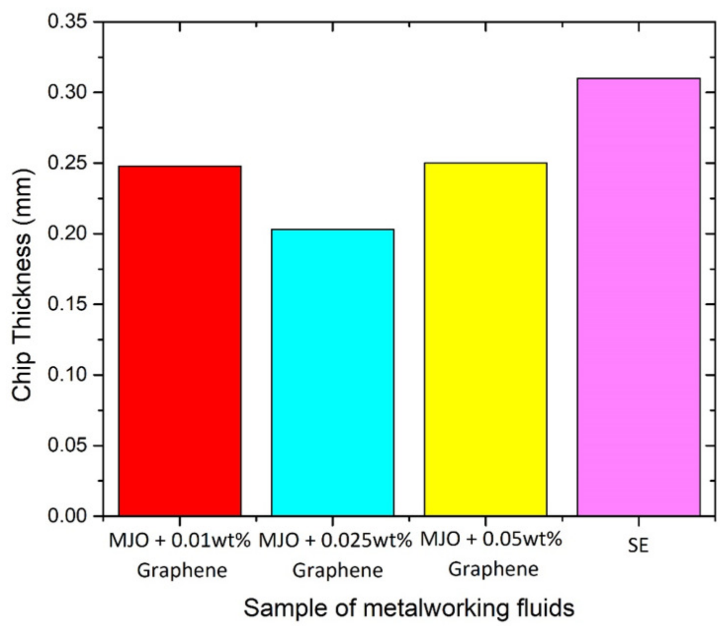

FIGURE 4. Graph of average chip thickness for each sample of metalworking fluids

CONCLUSION

In conclusion, all MJO nanofluid samples shows better machining performance compare to SE. The addition of 0.025wt% graphene nanoparticles in MJO based-oil delivered the best machining performance. It provides lower cutting temperature, lower chip thickness, and smooth workpiece surface roughness. This shows that 0.025wt% graphene concentration is a sufficient concentration which have higher thermal conductivity that could reduce cutting temperature and provide better lubrication film and rolling effect on the surface contact between cutting tool and workpiece. Lastly, based on the overall results, the presence of graphene in MJO remarkable as an excellent lubrication performance thus have a potential as a sustainable and environmentally friendly MWFs.

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