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Influence of XGnP as additives on properties of vegetable oil nanolubricant for machining process

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Abstract. Due to its biodegradability, less toxic, high lubricity and environmental friendliness, vegetable oils have been considered suitable alternative to conventional cutting fluid. Their efficiencies are however limited under aggressive machining. Thus, nanoparticles are introduced into base lubricating oils to improve their thermal and lubricating properties. This research study the thermal and lubricating properties of XGnP (exfoliated nanographene) nanolubricant at varying concentration of 0.35wt.%, 0.7wt.% and 1.05wt.%. KD2 Pro thermal analyser and LVDV-III Rheometer were used in measurement of thermal conductivity and viscosity of the nanolubricant respectively over temperature range of 30°C and 70°C. The four-ball wear and friction tester was used to measure friction and anti-wear property of the nanolubricant. Thermal conductivity and viscosity of nanolubricant improved with increase of nanoparticle concentration but decrease with increase of temperature. Thermal conductivity improvement at 30°C and 70°C are 15.5% and 7.6% respectively at highest concentration level of 1.05 wt.%. The tribological properties in terms of friction coefficient and anti-wear properties was observed to influence these properties of coconut oil for all concentration levels. Friction coefficient reduced by 10.8% in relation to the pure coconut oil at a concentration level of 0.35 wt% as well as reduction of wear scar diameter (WSD).

INTRODUCTION

Lubricants are used for friction reduction and wear of mechanical parts especially contacting surfaces during manufacturing process. Excellent lubricity, tribological properties, biodegradability and environmentally friendliness of vegetable oils made them a potential substitute for mineral oils in their application to machining industry [1-7]. However, vegetable oils as lubricants have been observed to be less efficient especially at extreme operating conditions due to their poor oxidative and thermal stability [2, 3, 8] and these deficiencies can be improved with modification of the base oil with either additive or chemical structure of the base oils [9-13]. Addition of nanoparticles is one of the ways base fluid are modified to improve their properties [13-16]. Nanofluids are colloidal suspension of nanoparticles in base fluids [17-20] and are capable of enhancing thermal conductivity and the convective heat transfer coefficient when compared to the base fluids [21-23]. Zhang et al [24] reported the significant improvement of friction-reduction and anti-wear properties of lubricating oil with Cu nanoparticles additives. Ahmed Ali et al [25] reported enhancement of thermophysical and tribological properties of nano-enhanced engine oil with addition of nanoparticles thereby reducing coefficient of friction and wear rate by about 50% and 30% respectively. As additives in lubricating oils, load carrying capacity of journal bearings were reported to improve significantly [26]. Dispersion of nanoparticle in

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oil influences performance of lubricating oils over their base fluid [27], as well as increasing concentration of nanoparticle enhances lubricating properties of nanolubricants [28, 29]. However, enhancement of tribological properties is not infinite as deterioration may occur at higher level of concentration due to agglomeration and that the shape and size of nanoparticles dispersed in oil have considerable influence on the tribological properties because larger particle size [29, 30].

Reports from literature on the application of vegetable oil based nanolubricants in various machining processes [12, 13, 31-41] indicated superior performance over the base oil in terms of friction and wear reduction, heat dissipation and improved surface finish. The superior performance of the nanolubricants are attributed to the enhanced thermal and tribological properties over the base oil. Few researchers in the metal cutting and allied researches have evaluated thermal conductivity and viscosity [12, 38, 39, 42] and tribological properties [13, 42-45] of vegetable oil nanolubricants. However, these enhanced properties of vegetable oil nanolubricants in machining applications are rarely evaluated for proper understanding of improvement level of the base fluid in which they have been dispersed and thus, the need to extensively evaluate especially thermal conductivity of vegetable oil nanolubricants over wide range of temperatures is necessary since previous studies reported thermal conductivity of vegetable oil lubricant at room temperature or about 30°C. Therefore, this current work aims at evaluating the thermos-physical properties of vegetable oil based nanographene lubricant over arrange of temperature to enable proper understanding of temperature variation on the behaviour of nanolubricants.

NANOFLUID PREPARATION AND MEASUREMENT OF PROPERTIES

Exfoliated nanographene particles of less than 10nm and coconut oil are used in formulation of the nanofluids at varying concentration levels of 0.35, 0.70 and 1.05 wt.%. The two-step method of nanofluid preparation as used by Su et al [45] was adopted in the dispersion of silicon carbide nanoparticles into coconut oil and manually stirred for few minutes before subjecting it to the silverson multifunctional L5 series for homogeneous of nanofluids for 1hr 40mins at rotational speed of 3200rpm. Silverson L5M mixer is found suitable for mixing, emulsifying, disintegration, dissolving etc of particles within the base fluids. The prepared nanolubricant at varying concentration levels were evaluated for their influence on the thermos-physical and tribological properties of base fluid.

Thermal Conductivity of Nanolubricant

KD2 pro thermal property analyser apparatus which is in conformity with both standards of ASTM D5334 and IEE 442- 1981 was employed to measure thermal conductivity of the base fluid and the formulated nanofluids. The apparatus consists of a handheld (power control) and sensor for measuring the thermal conductivity of the fluid in a controlled constant temperature environment using a water bath within accuracy of 0.1°C. The needle sensor (KS-1) is usually calibrated with determination of thermal conductivity of glycerine with ±5% deviation. Five sets of readings for each sample were taken at interval of 15mins each and the average value considered for the temperature range of 30°C to 70°C.

Viscosity of Nanolubricant

Viscosity of fluids are measured with the aid of Brookfield LVDV III Ultra Rheometer incorporated with a circulating water bath which is capable of measuring viscosity in the range of 1 to 6000000 mPa.s. A Rheocal programme is used in acquiring the data at specified temperature and torque for each measurement. Viscosity of samples are measured for a temperature range of 30°C to 70°C. 16ml of a sample to be evaluated is placed in the cylinder jacket and the entire unit is attached to the rheometer after the sample is heated with a sensor to the specified test temperature. Minimum of 3 experimental trials for each test temperature are taken with an average value considered for analysis.

Tribological Properties of Nanolubricant

Tribological behaviour of coconut oil and nanofluids of varying concentration are evaluated for wear and friction using the four-ball wear test according to ASTM D4172-94 method. Wear preventive properties and coefficient of friction of the lubricants are evaluated using steel ball (AISI 52100) of diameter 12.7 mm and a hardness value of

62HRC. Three (3) steel balls are submerged in 10ml of lubricant in a collet pot and clamped under a rotating spindle used to hold the upper steel ball pressed against the steel balls firmly held together immersed in the lubricant under test. The test load, time, temperature and speed of rotation selected in accordance with standard test schedule for this study are 392 N, 60mins, 75°C and 1200rpm respectively.

RESULTS AND DISCUSSIONS

Influence of XGnP Additives on Thermal Conductivity

Figure 1(a) shows that thermal conductivity of nanolubricant decreases with increase of temperature but increase of concentration is responsible for enhancement of thermal conductivity of nanolubricant. The inclusion of nanoparticles improved the weakened intermolecular forces of pure base oil thereby strengthening nanolubricant to be more effective in lubrication. The revelation from this study agrees with previous research by Krishna et al [12] and Padmini et al [38] when they evaluated the effect of nanoparticle additives on thermal conductivity of coconut oil with nanoboric and molybdenum sulphide nanoparticles at 30°C as shown in Fig. 1(b).

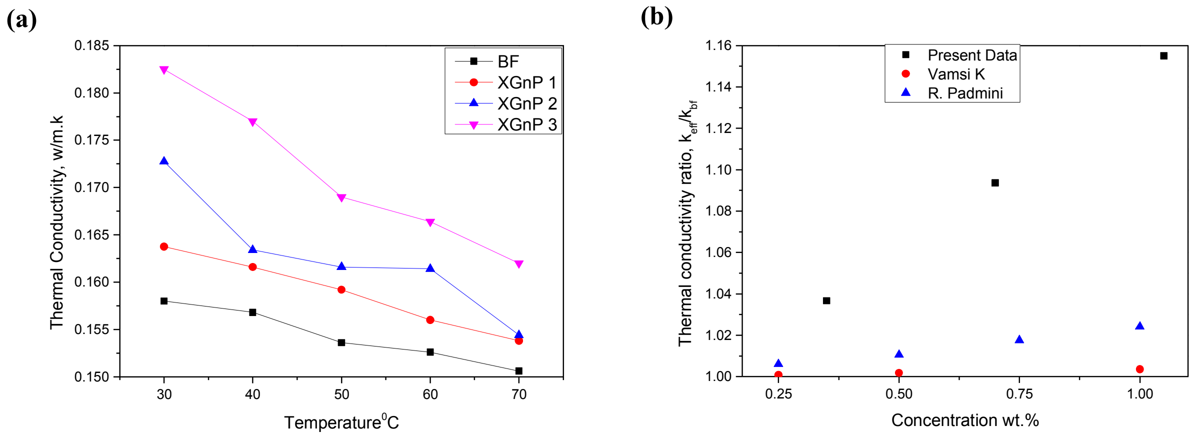

FIGURE 1. (a) Thermal conductivity variation with temperature under. (b) Effect of additives concentration on thermal conductivity at 30°C in comparison with previous researchers.

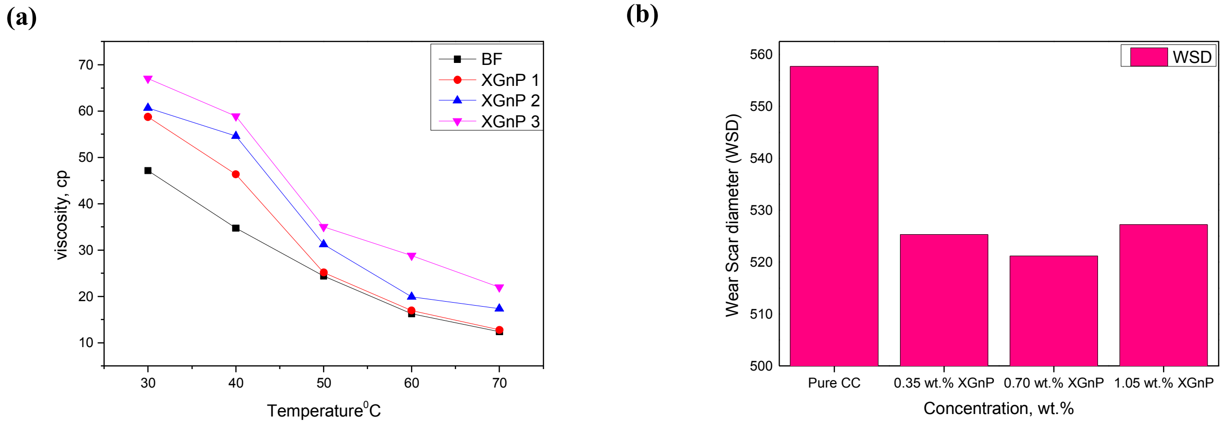

FIGURE 2. (a) Variation of viscosity with temperature and concentration of nanolubricant, (b) Influence of particle concentration on the anti-wear properties of nanolubricant

Influence of XGnP Additives on Viscosity

Viscosity of nanolubricant decrease with increase of temperature but increase with increase of particle concentration as shown in Fig. 2(a) The weakened intermolecular forces of lubricant with increase of temperature as observed by Padmini et al [38] is improved with increased nanoparticle inclusion to vegetable oils. Thus, increase of concentration strengthened the formation of lubricating film between contacting surfaces thereby reducing friction and substantially dissipating heat from contacting zone.

Influence of XGnP Additives on Anti Wear Properties

Wear preventive characteristics of the nanolubricant were evaluated for varying concentrations and all concentration levels indicated superior performance over the pure base oil as shown in Fig. 2(b) Lower wear scar diameter signifies better wear preventive properties and from the result of the wear test shows that at all level of concentrations, the wear preventive property improved significantly over the pure coconut oil.

CONCLUSIONS

Influence of XGnP nanoparticles as additives on the properties of vegetable oil nanolubricant have been evaluated. Thermo-physical and lubricating properties of the nanolubricant prepared at concentrations levels of 0.35, 0.70 and 1.05wt.% indicated superior performance of XGnP nanoparticle inclusion into lubricant. Thermal conductivity of nanolubricant was observed to decrease with increase temperature but increases with increased concentration level while viscosity increases with increase of volume concentration and decrease with increase of temperature. The highest thermal conductivity enhancement ratio was observed to be 1.15. Increase of concentration increase the viscous nature of the fluid under temperature variation thereby strengthening the ability of vegetable oil based nanolubricant to form lubricating film between contacting surfaces that aid friction reduction and faster dissipation of heat when compared with pure vegetable oil that disintegrate under higher temperature. The lubricating property indicated improve wear preventive properties at all level of concentration of nanolubricant as measured by WSD. XGnP nanoparticle as additive in vegetable oil has shown better thermos-physical and lubricating properties and will be a promising machining lubricant.

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