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# FRICTION AND VIBRATION ANALYSIS OF SLIDING SURFACES LUBRICATED BY ENGINE OILS DISPERSED BY ALUMINUM OXIDE NANOPARTICLES

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## ABSTRACT
**The present investigation is focusing on the enhancement of tribological properties of 20W-50 engine oil by the addition of $Al_2O_3$ nanoparticles. The frictional property of engine oil was investigated by tribometer using stainless steel disc and plate. It was found that $Al_2O_3$ added to engine oil enhanced coefficient of friction significantly and reduced vibrations. The study concluded that the lowest coefficient of friction was obtained at 0.4 wt. % concentration of $Al_2O_3$ nanoparticles and working temperature of 50 °C. The lowest and highest acceleration values were detected for oil at 50 and 100 °C operating temperatures respectively.**

## KEYWORDS
**Friction, vibration analysis, $Al_2O_3$ nanoparticles, lubricant additives, engine oils.**

## INTRODUCTION
**The tribological characteristics of the 5W-30 engine oil by adding CranAlc MAX Nano lamella was studied, [1]. The anti-wear resistance of engine oil were examined by four-ball test device using stainless steel balls. The results obtained were compared with h-BN and $MoS_2$ nanoparticles that included 5W-30 engine oils. The added $Cr_2AlC$ fluid (modified lubricant) significantly enhances anti-wear properties and increases the strength of the oil film (OFS) from the base oil to approximately three times. The performance of Nano-lanthanum hydroxide/reduced graphene oxide compounds (Nano-la $(OH)_3$/RGO) has been successfully studied as anti-wear additives for diesel engine oil, and the results indicate that Nano-la $(OH)_3$/RGO compounds can significantly improve performance diesel engine oils under boundary lubrication conditions, [2]. In particular, the wear resistance performance of diesel engine oil increased by 44 % after the addition of a compound by 0.1% by weight at 80 ° C and contact pressure of 1.62 GPa. Huawei Wu et al.**

**A study aimed to evaluate the thermal experiment for the thermal conductivity of mixed nanofluoride from zinc oxide (ZnO) and multi-wall CNT (MWCNT) in engine oil (SAE**

**10W40), [3]. The effects of the concentration of nanoparticles as well as the temperature of the liquid are evaluated. Experiments were conducted at a temperature between 25 and 50 °C and the nanoparticle fraction size from 0.05 to 0.8%. Experimental results showed that a higher percentage of thermal conductivity of lubricating nanoparticles is achieved to obtain a higher portion size and temperature of nanoparticles. The mechanics behind high friction using an integrated methodology, based on atomic force microscopy (AFM) and optical X-ray spectroscopy (XPS) were examined, [4, 5]. The use of the analytical contact mechanics model shows that the compression coefficient of the border shear force, measured using a lateral force microscope, provides an explanation for the observed increase in friction measured on a micro-scale.**

**Presentation of a feasibility study for the use of a new nanoparticle oil containing a mixture of MWCNT - nanoparticles arranged by 30 - 70% was introduced, [6]. The results of the experimental study showed a significant reduction in the viscosity of motor oil nanoparticles (as compared to the viscosity of pure 5W50 oil) after the addition of 0.05% and 0.1% of nanoparticles to 5W50. Reducing the viscosity reduces the damage caused by starting the engine in case of cold start. The results of test activities performed on a fully formulated motor oil incorporating $MoS_2$ nanoparticles were described, [7]. Nanoparticles were allowed to appear in the new European driving cycle (NEDC) to reduce fuel consumption by 0.9 % for reference lubricants without the presence of nanoparticles. It was observed that both the wear resistance and high-pressure properties of castor oil specimens were enhanced with the addition of ZnO nanocomposition rates to a certain concentration of zinc oxide nanoparticle friction rates (0.1 %), which were then not significantly improved in coefficient of friction observed but increased wear rate, [8]. The formation of a triple-core film due to adsorption and adherence to nano-friction rates on surfaces was responsible for reducing corrosion properties.**

**The dispersal of MWCNTs nanoparticles and zinc oxide nanoparticles containing a fraction of 0.005% and 0.02%, respectively, were studied together with surface gum Arabic in SAE 20W40 engine oil, [9]. Tribological properties such as wear resistance, friction coefficient and thermal-physical properties such as thermal conductivity, viscosity, and flash point for nano-lubricating oils were evaluated and compared with normal engine oil properties. Thus, the results show that the marked improvement in the operational properties of engine oil is due to the dispersion of nanoparticles in it. It was observed that the viscosity of nanofluid increases with the reduction of solid volume fraction, [10]. Moreover, it was found that as the temperature rises, the viscosity of the nanofluids decreases, and they are more noticeable at lower temperatures. Comparison of experimental results with theoretical models showed that these models failed to predict the correct viscosity values of nanofluids in all solid volume fractions. Experimental data also indicated that the maximum viscosity of nanofluid was 132% compared to the base fluid. The mixing of $TiO_2$ nanoparticles in engine oil significantly reduces the rate of friction and corrosion and thus improves the lubricating properties of engine oil, [11, 12]. The analysis of $TiO_2$ nanoparticle dispersion in lubricating oil using a UV spectrometer shows that $TiO_2$ nanoparticles have good stability and solubility in lubricant and improve lubricating properties of engine oil.**

**The effect of adding $SiO_2$ and $TiO_2$ nanoparticles to mineral oils (20W-50) and (15W-50) on the tribological behavior was carried out using tribometer setup under different working temperatures, 40, 80 and 100 ˚C, [13]. The friction coefficient and wear rate reduce with lubricant oils of 1.0% wt. of $TiO_2$ content. While, oil samples contain of $SiO_2$ nanoparticles have not a great role in improving of the tribological behavior, [14]. The variation of the concentration of $Al_2O_3$ nanoparticles with jojoba oil was assessed for tribal properties. It was observed that the minimum coefficient of friction and corrosion at a concentration of 0.1% is increasing at a concentration of 0.15 % and the maximum corrosion was obtained at a concentration of 0.2%.**

**It was aimed to study the effect of the addition of $Al_2O_3$-$Fe_2O_3$ hybrid Nano powder on the thermal properties of 10w40 engine oil, [15]. The results indicated that even the smallest concentration of the mass improves the thermal properties of lubricating nanoparticles. A study to assess the tribological properties of ZODDP as a diacosyl sepakate additive (DIOS) in steel and aluminum contacts on the ball scale on the disc was carried out, [16]. Compared with ZDDP, the friction coefficient and corrosion rate of ZODDP decreased by 10.37 % and 71.74 % respectively, [17]. Al-SiC-nAl2O3-WS2 was prepared by powder metallurgy method and nano-alumina by combustion process solution.**

**The present work aims to enhance the tribological properties of 20W-50 engine oil by addition of $Al_2O_3$ nanoparticles. The frictional property of engine oil was investigated by tribometer using stainless steel disc and plate.**

## EXPERIMENTAL

### The Tribometer Test-Rig

**Friction tests were performed experimentally using a tribometer. It is designed to simulate, evaluate and test almost all types of oil, as shown in Fig. 1. The testing machine contains aluminum friction plates used to measure friction force. Engine oil was used without additive as reference lubricant. Tests were performed using flat-panel pin specimens in the contact area, where the applicable rotational speed was from 1,000 to 3,000 rpm. Experiments were conducted using the tested oil heated to 50, 75 and 100 ˚C temperatures. Before each test, the disc holder and the lifting stand were cleaned to get rid of unwanted materials such as foil or lubricants stuck to the contact surfaces. The test was generally used as a comparative test in which the coefficient of friction is measured over the specimens to be studied. The vibration setting is used in this work to record velocity and acceleration signals to study the acceleration generated by a different mechanism with a five-band vector. Optical coding is used to measure shaft speed. Thus, the rotational speed of the shaft is known directly from this console reading. Flexible clutch coupling is used to remove the high-frequency vibration caused by the motor. Two balls are installed in solid housings. Accelerometers (IMI Sensors- 603C01) are installed on a tested bearing housing to measure acceleration signals in two directions. A data acquisition card (BMC USB-AD16F) is used to collect signals.**

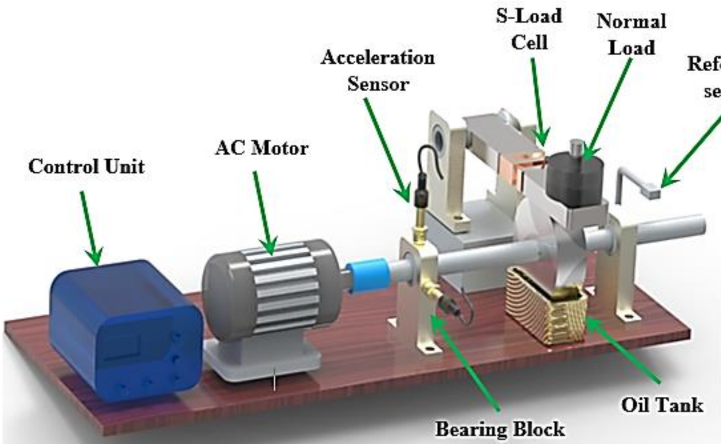

**Fig. 1 Representation of the tribometer and vibration test rig.**

**Preparation and Fabrication of Specimens**

**Engine oil (20W-50) is used. Then, concentrations of $Al_2O_3$ nanoparticles of 0.1, 0.2, 0.3 and 0.4 wt. % were used. Good stirring was taken into consideration to ensure uniform distribution of the nanoparticles in the tested oil oil. Figure 2 shows test specimens of lubricating oils mixed in different temperatures, where the temperatures of the mixing process was 50, 100 and 150 ˚C in order to study the effect of the mixing temperature on the friction coefficient and the damping ratio in the resulting vibrations.**

**Fig. 2 Oil samples mixed with $Al_2O_3$ nanoparticles at temperature (a) 50˚C, (b) 100˚C and (c) 150˚C.**

**RESULTS AND DISCUSSION**

**Engine oil acts as a lubricant by reducing the friction coefficient between the sliding parts of the engine and thereby reducing fuel consumption. It also acts as a coolant by carrying excess heat away from the moving parts of the engine, Fig. 3. The heat stored in large quantities of engine oil is usually higher than the thermal conductivity that leads to the**

**formation of oil sludge inside the engine in extreme conditions and increases the chances of burning engine oil and thus producing a large amount of smoke.**

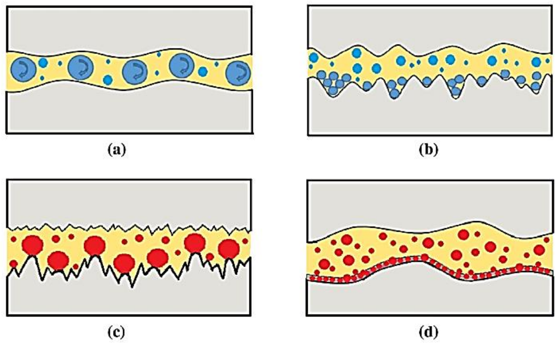


**Fig. 3 Different mechanisms for the tribological performance using nanoparticles (a) rolling mechanism; (b) mending mechanism; (c) polishing mechanism; (d) protective film, [18, 19].**

**Analysis of Friction Coefficient**

**The effect of friction coefficient was studied with different speeds for a set of test specimens of engine oils to which a percentage of $Al_2O_3$ nanoparticles were added. Figure 4 shows the effect of the friction coefficient at different velocities of the tested specimens at 50°C. The specimens were mixed at 50°C. It was observed that the friction coefficient significantly decreased with an increase in the content of $Al_2O_3$ nanoparticles. The $Al_2O_3$ contents 0.1 and 0.2 wt. % are closely related. There has been a clear reduction of the friction coefficient for 0.4 wt. % content at relatively high speeds under all operating temperatures and this may be due to rolling effect of nanoparticles generated at the rubbing surfaces. The $Al_2O_3$ nanoparticles may be able to form a thin- layer between asperity contacts helps to reduce of the shear stress and friction coefficient to prevent the metal-metal contact. Generally, with the increase in operating temperatures, an increase in the friction coefficient is observed, while the decrease in the coefficient of friction with the increase in the ratio of the $Al_2O_3$ nanoparticles was dominating, Fig. 5. This may be due to lower viscosity of the engine oil when operating temperature increased.**

**Figures 6 and 7 show a lower value of coefficient of friction for all contents of $Al_2O_3$ than that observed for tested oil free of nanoparticles. The lowest coefficient of friction for all concentrations values were observed at 100°C mixing temperature at 0.3 wt. % $Al_2O_3$ nanoparticles. It was observed that the lowest friction coefficient was reached at 50°C working temperature. It can be concluded that, at different temperatures and rotational speeds, $Al_2O_3$ nanoparticle additives with concentration of 0.3 wt. % at 100°C mixing temperature can efficiently improve the lubricating properties of the engine oil.**

**At 150°C mixing temperature, Figs. 8 and 9, friction coefficient of the highest $Al_2O_3$ content was close to the friction coefficient of pure oil, while the lowest friction coefficient was at 0.2 wt. % $Al_2O_3$ nanoparticles.**

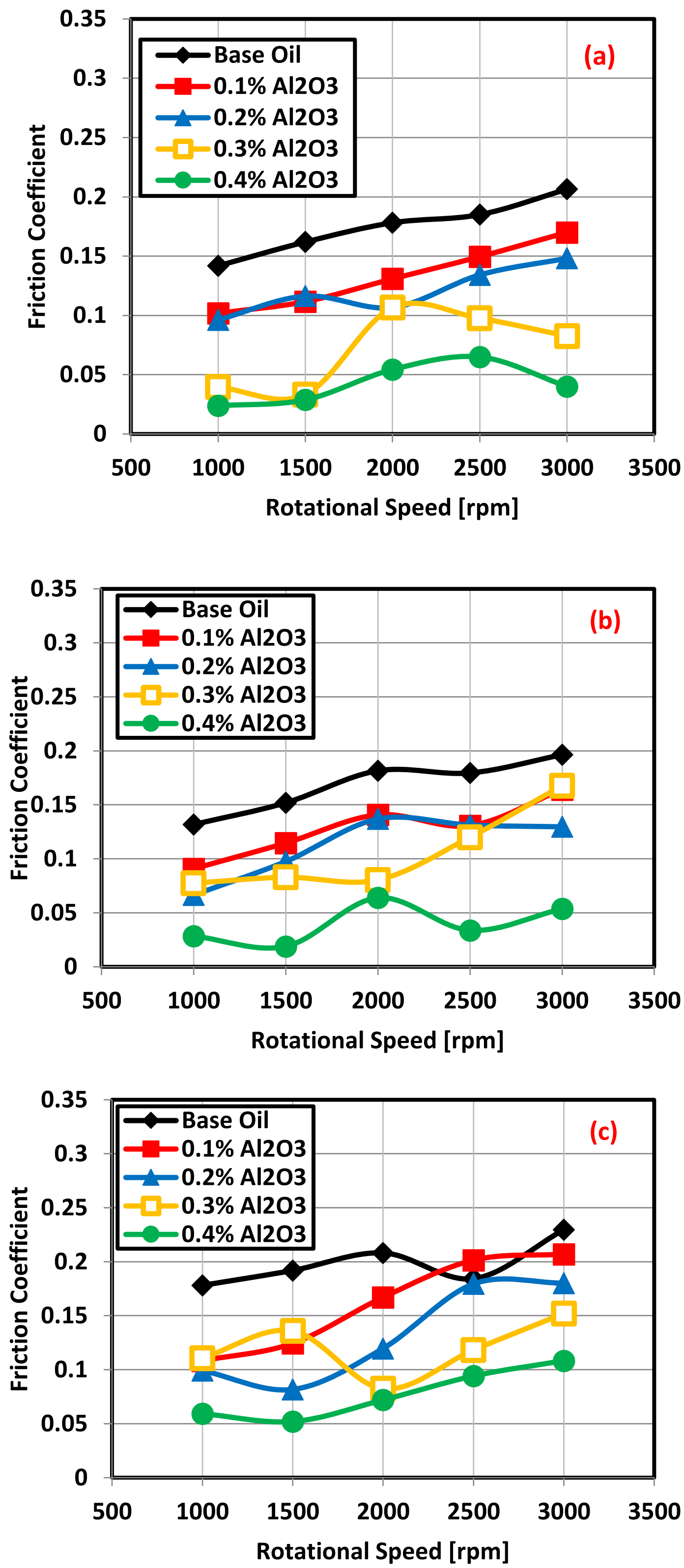


**Fig. 4 Friction coefficient with different rotational speed for $Al_2O_3$ mixed at temperature 50˚C and operating at temperatures (a) 50˚C, (b) 75˚C and (c) 100˚C.**

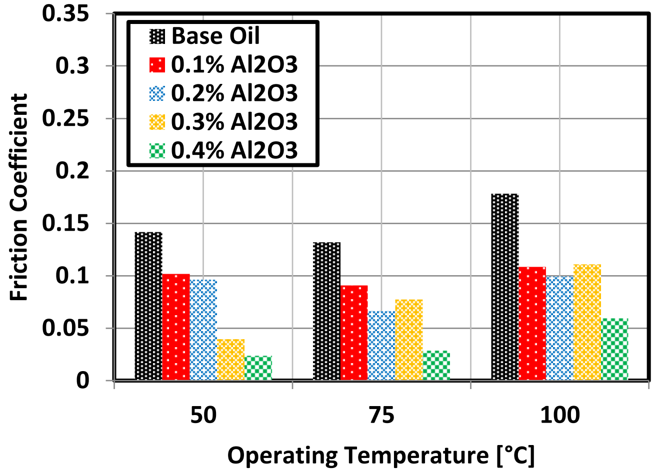


**Fig. 5 Friction coefficient observed at different operating temperatures at 50˚C mixed temperature.**

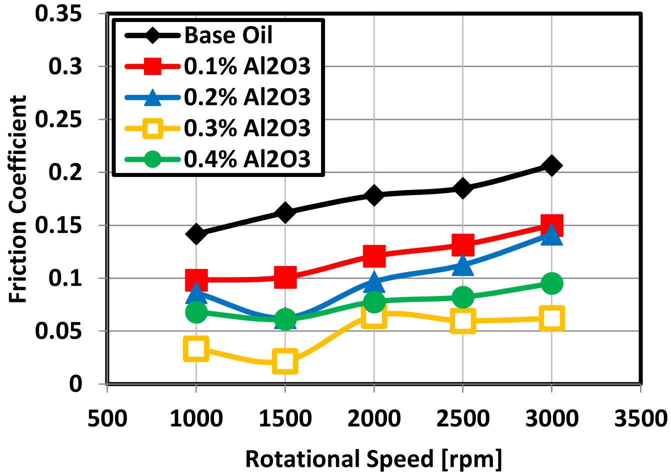


**Fig. 6 Friction coefficient Friction coefficient with different Rotational Speed for $Al_2O_3$ mixed at 100˚C temperature and operating at 50˚C temperature.**

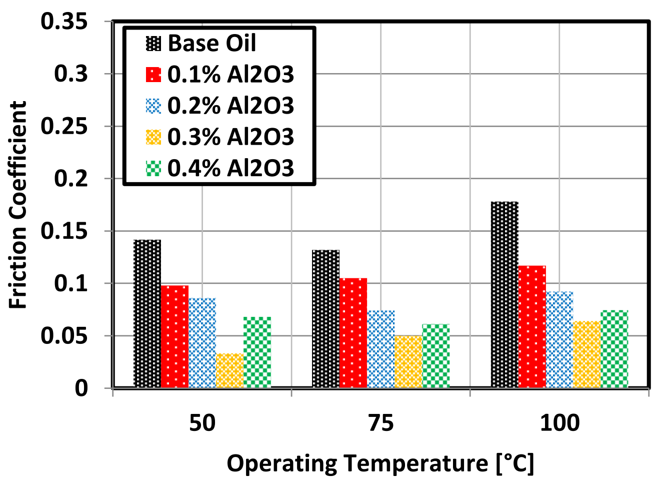


**Fig. 7 Friction coefficient observed at different operating temperatures at 100˚C mixed temperature.**

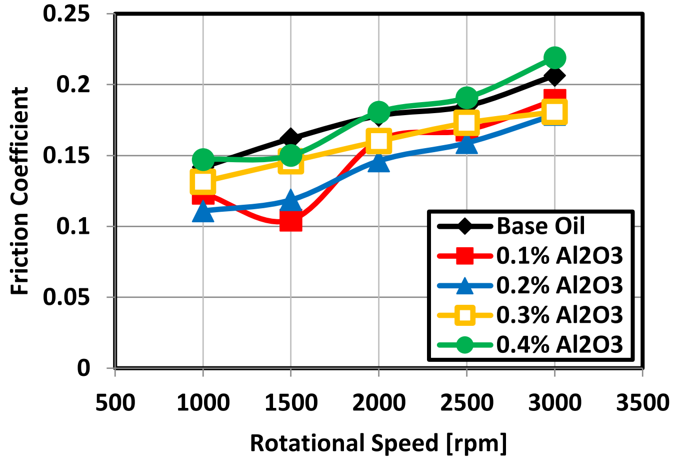


**Fig. 8 Friction coefficient with different rotational speed for $Al_2O_3$ mixed at 150ºC temperature and operating at 50ºC temperature.**

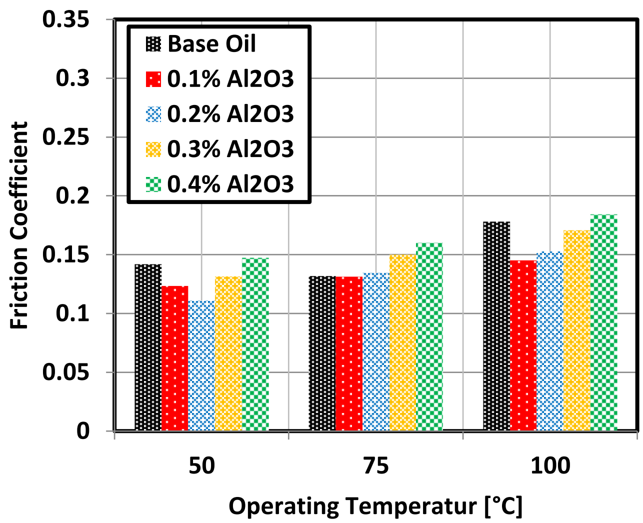


**Fig. 9 Friction coefficient observed at different operating temperatures at 150˚C mixed temperature.**

**To find out the effect of the mixing temperature of nanoparticles on the friction coefficient, a comparison was made. The various samples content of $Al_2O_3$ nanoparticles, is carried out under operating conditions of a speed of 1000 rev/min and operating temperature of 75˚C, as illustrated in Fig. 10. It can be observed that the increasing of mixing temperature leads to increase of the friction coefficient with all content adding. It may be due to the increase in temperature, which reduces the oil viscosity, which impedes the dispersion and the suspending of nanoparticles through the oil. Therefore, it is possible to notice the presence of the particles deposits in the bottom of the container. The particles agglomerating will lead to rise oil thickening, which causes an increase in the friction coefficient of the bearing surfaces. Therefore, it can be concluded that 50˚C is the best mixing temperature.**

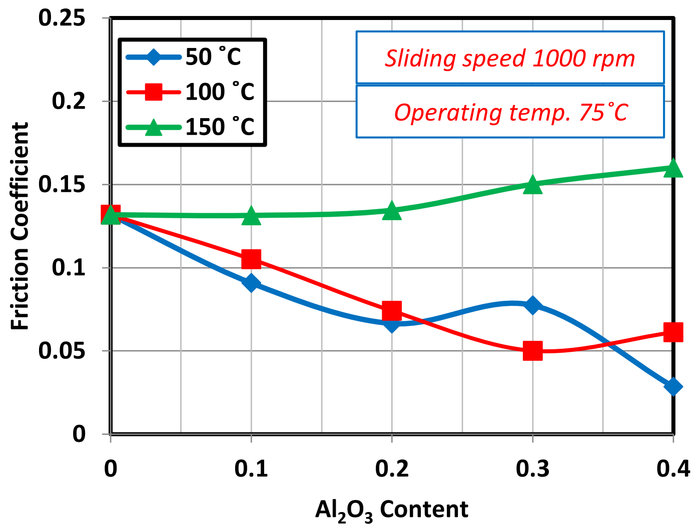


**Fig. 10 Comparison of the effect of mixing temperature on the friction coefficient at different $Al_2O_3$ content**

**Analysis of Vibration**

**The value of the acceleration with the different rotational speed of the oil mixed with the nanoparticles at 50 °C temperature is shown in Figs. 11 and 12. It was observed that the lowest value of the acceleration was recorded at 0.4 wt. % $Al_2O_3$ content at 50 °C working temperature due to the high viscosity of the oil maintaining at the lower temperature. The highest value of vibrations was recorded for oil free of nanoparticles, where the increase in the content of nanoparticles was followed by an increase in the value of damping. The lowest value of acceleration amplitude (RMS) was obtained at 0.4 wt. % $Al_2O_3$ content and at 50 °C working temperature, while the highest vibrations reached at clean oil at 100 °C working temperature due to the low viscosity.**

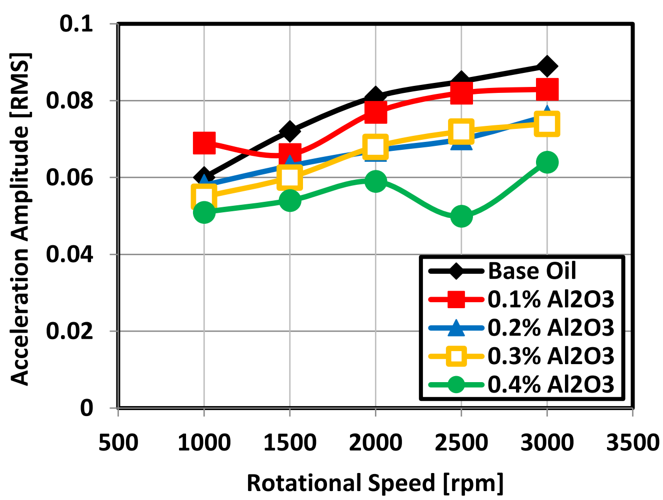


**Fig. 11 Acceleration Amplitude [RMS] with different rotational speed for $Al_2O_3$ mixed at 50°C temperature and operating at 50°C temperature.**

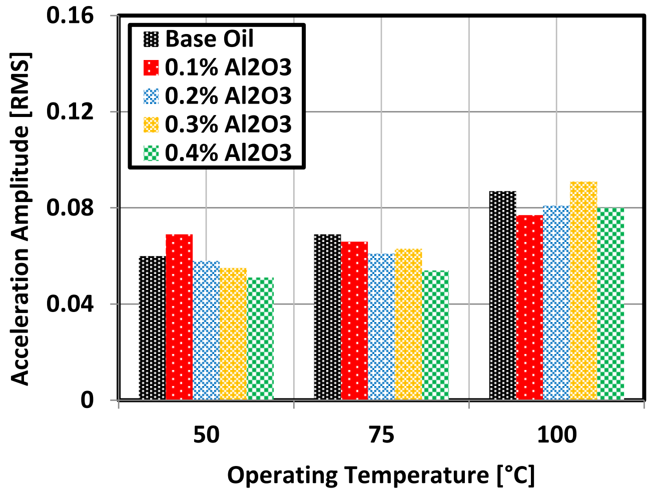


**Fig. 12 Comparison between different operating temperatures for oil at 50°C mixed temperature.**

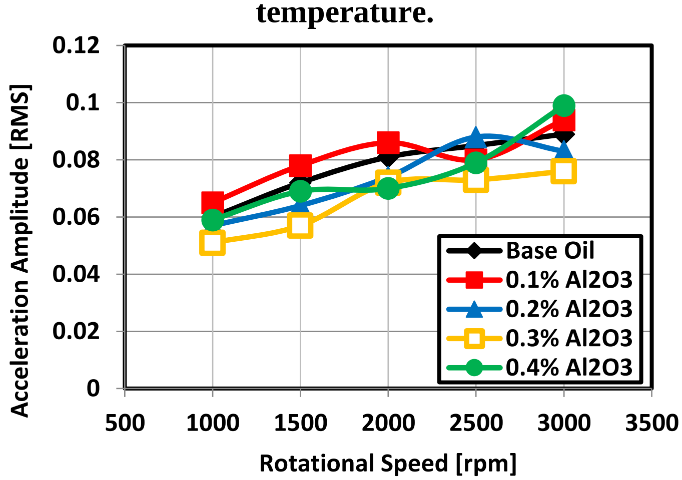


**Fig. 13 Acceleration amplitude [RMS] with different rotational speed for $Al_2O_3$ mixed at 100°C temperature and operating at 50°C temperature.**

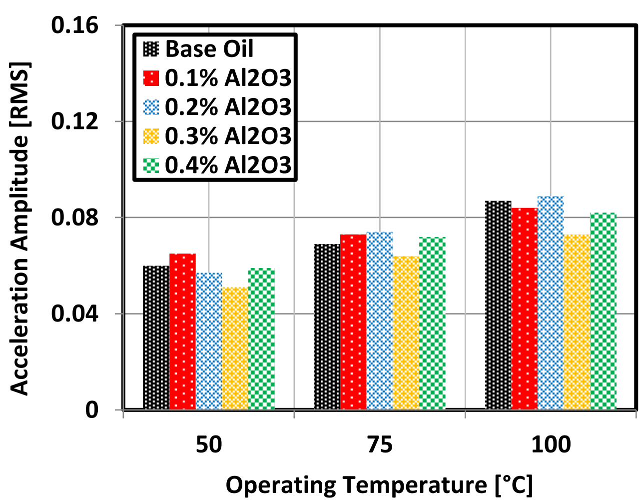


**Fig. 14 Comparison between different operating temperatures for oil at mixed 100°C temperature.**

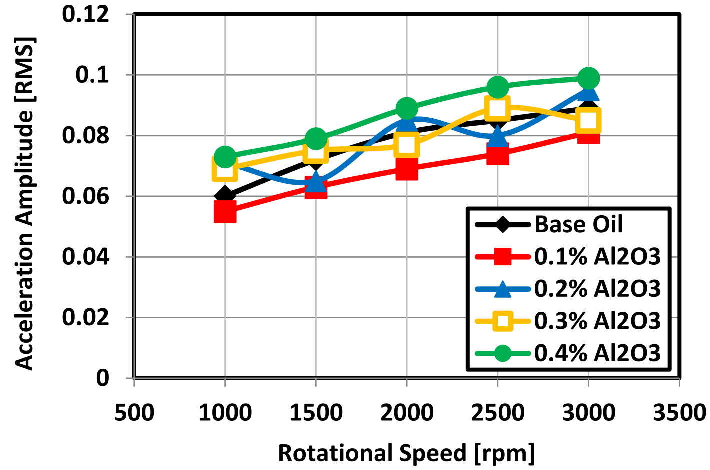


**Fig. 15 Acceleration amplitude [RMS] with different rotational speed for $Al_2O_3$ mixed at 150°C temperature and operated at 50°C temperature.**

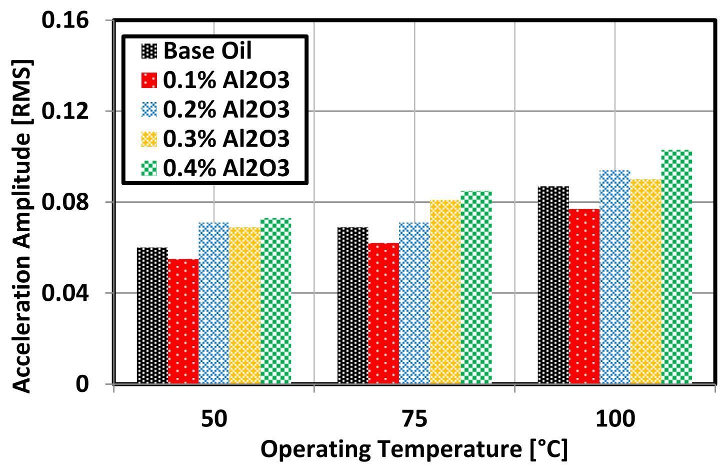


**Fig. 16 Comparison between different operating temperatures for oil at 150°C mixed temperature.**

**The variations of acceleration amplitude [RMS] with different rotational speed for $Al_2O_3$ mixed at temperature 100 and 150°C are shown in Figs. 13 – 16. At mixing temperature of 100°C, it can be observed that the oil of 0.3 wt. % $Al_2O_3$ content has lowest RMS values. While it is illustrated, for samples mixed at temperature 150°C, that the acceleration amplitude (RMS) was measured at 0.4 wt. % $Al_2O_3$ content higher than the base oil and the lowest vibrations occurred at 0.1 wt. % $Al_2O_3$ content.**

## CONCLUSIONS

**The tribological behavior and vibration (RMS) of engine oil at different operating temperatures and different $Al_2O_3$ nanoparticles content was studied. It was found that addition of nanoparticles were found to advance the tribological properties of the existing commercial engine oils (20W - 50). The prepared lubricating oils were found to be stable in the entire analysis period. In addition, the study concluded that the lowest coefficient of friction was reached when mixing under a temperature of 50 ° C and at 0.4 wt. % $Al_2O_3$**

**content at a working temperature of 50°C. In contrast, the highest friction coefficient was reached when mixing under a temperature of 150 °C and 0.4 wt. % $Al_2O_3$ content at working temperature of 100 °C. The lowest acceleration amplitude (RMS) at mixing was 50 °C, 0.4 wt. % $Al_2O_3$ content at 50°C operating temperature. The highest acceleration amplitude (RMS) at mixing was 150 °C, 0.4 wt. % $Al_2O_3$ content and 150 °C operating temperature.**

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