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Characterization and Analysis of Rheological Behaviour with Prepared Nano-Cutting Fluids from Al_2O_3 and TiO_2

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Abstract

In this research paper, an attempt has been made to characterize and analyse the rheological properties of two samples of nano-cutting fluids. Nanoparticles of Al_2O_3 and TiO_2 were characterized by SEM and EDS. The high peaks showed the respective presence of aluminium, oxygen for alumina and titanium and oxygen for titanium dioxide. The two samples of nano-cutting fluids were prepared. Alpha alumina, α-Al_2O_3 nanoparticles were used for the preparation of the sample of nano-cutting fluid in the ratio of 1% (w/w) with distilled water. TiO_2 nanoparticles were used for the preparation of nano-cutting fluid in the ratio of 1% (w/w) with distilled water. Conventional cutting fluid was made in the ratio of 1:20 (w/w) with distilled water. The three samples were analysed at room temperature 25°C and 65°C. It was found that viscosity of each sample was lower at higher temperature as compared to viscosity at 25°C. The thermal conductivity of each sample was increased at higher temperature by 10.91, 8.42 and 7.4% respectively as compared to low temperature.

Keywords: *Nano-cutting fluids; Nanoparticles; Temperature; Viscosity*

1. Introduction

The researchers and scientists are meticulously working in reducing the values of machinability characteristics between the workpiece and cutting tool (i) surface roughness of the machined workpiece, (ii) cutting forces, (iii) coefficient of friction, (iv) tool wear, (v) cutting temperature etc. [1, 2]. The attempts are made that coolant used during machining may not generate any harmful effect towards the operator and environment. Cryogenic cooling with liquid nitrogen has been used by researchers. This is environment friendly and does not produce any toxic effects on the operator [3, 4]. The conventional cutting fluids might produce fumes, itching to eyes skin etc. and various other types of human health issues problems during machining processes. The direct disposal of used one might not be environmentally friendly. The edible and non-edible oils have been used during machining processes. The health issue problems related to operator and pollution to the environment might have been improved [5-9]. Silver nanoparticles were mixed in conventional cutting fluid and it was found that surface roughness and tool wear reduced [10]. The nano boric powder was mixed in vegetable oil samples of coconut oil and soyabean oil and it was found that nanoparticles reduced the surface roughness and tool wear as compared

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to dry and wet machining with conventional cutting fluid [11-14]. The vegetable oil and compressed air mixed in a closed chamber are supplied at the interface of the workpiece and cutting tool. The minimum quantity lubrication prevented the excess flow of coolant and supplied the controlled amount of coolant [15]. Nanoparticles are very fine particles of the magnitude of 10^{-9}m. The lubrication, cooling and abrasive properties are dependent on the types of nanoparticles. The heat transfer and tribological properties improved. The faster rate of heat transfer may keep the tool and workpiece at a lower temperature. This further might reduce the coefficient of friction and wear rate [16-19]. Padmin et al. [20] made samples of nano MoS_2 with (0, 0.25, 0.5, and 0.75%) (w/w) in coconut oil and performed experiments on lathe machine and it was found that 0.5% of composition gave a better results as compared to other compositions. Uysal et al. [21] prepared a composition with MoS_2 1.0% (w/w) with vegetable oil with water emulsion during milling and found better surface finish than conventional cutting fluid. Kumar et al. [22] developed a nanofluid by using multi-walled nano carbon tubes in sunflower by 1% (w/w). The experimentation was performed on a turbometer and grinder. It was found that tribological properties got improved as compared to a conventional cutting fluid. Amrita et al. [23] prepared various samples of nanofluids by using nanoboric acid, nano molybdenum disulphide with emulsion 0.3% (w/w). It was found that functionalised nano graphite showed good stability in oil emulsion. Sharma et al. [24] prepared different types of samples of nano-cutting fluids with Al_2O_3 (0, 0.25, 0.5, 1.5, 2.0 and 3%) (v/v) with deionised water and found that with 1% composition gave a better performance during turning operations as compared to other compositions. Ramakrishanan et al. [25] found that marginal difference in surface roughness between experimentation performed on lathe machine during 0.5% and 1.0% (w/w) Al_2O_3 nanoparticels with inonized water as coolant. The tool wear was lower with 1.0% (w/w) nano-cutting fluid as compared to dry and 0.5% (w/w) concentration of Al_2O_3. The novelty of this research work is that an attempt has been made to focus on characterization of naoparticles, prepared nano-cutting fluid and the rheological property of nano-cutting fluid like viscosity has been analysed with time period of constant shear rate at two different temperatures like room temperature 25°C and 65°C and compared to conventional cutting fluid. The highly viscous cutting fluids may not be suitable for machining as they may not be able to reach properly at the interface of workpiece and cutting tool and very lean cutting fluid may not provide a good lubricating and cooling effect. The thermal conductivity of nano-cutting fluid was measured and compared to conventional cutting fluid. Therefore, nano-cutting fluids with Al_2O_3 and TiO_2 were prepared characterised and analysed for viscosities at a different temperature.

2. Experimental Methodology

2.1 Sample preparation

Two different types of nanoparticles like (α-Al_2O_3) alpha-alumina and titanium dioxide (TiO_2) were procured from the manufacturers Plasma ChemGmbH, Berlin, Germany. The nanoparticles are water-soluble. The properties of nanoparticles are given in Table 1. The purity index of nanoparticles was very high in terms of percentage for both the selected nanoparticles.

Table 1: Properties of nanoparticles

	Properties	Nano-Al_2O_3	Nano-TiO_2
1	Average grain size	40nm	8nm
2	Particle size full range	5-100nm	8-25nm
3	Purity	99.99%	99.98%
4	Specific surface	> 10 m^2/g	50±10 m^2/g

2.2 Process involved in nano-cutting fluid and conventional cutting fluid

Two samples of nano-cutting fluids were prepared from two different nanoparticles. The composition was formed by considering the weight by weight ratio with base fluid. In present research work base fluid was distilled water. The empty beaker was weighted on weighing scale. Then scale reading was made zero. The beaker was filled with distilled water and weighed on a scale. Now, nanoparticles were weighed on micro-scale in proportionate to 1% weight of water and mix in beaker.

2.2.1 Nano-cutting fluid with TiO_2 nanoparticles

Nanoparticles of TiO_2 were weighed on micro digital balance with an accuracy of ±0.0001 grams. A sample of nano-cutting fluid was made with distilled water in the proportion weight of 1% (weight by weight) of distilled water. Fig. 1 shows a magnetic stirrer for blending of nano-cutting fluid for 60 minutes at 520 rpm at 21°C and rest was given for half an hour. Rest was given for half an hour for checking the sedimentation. The process of magnetic stirring was repeated for 60 minutes. This process was repeated 4-5 times.

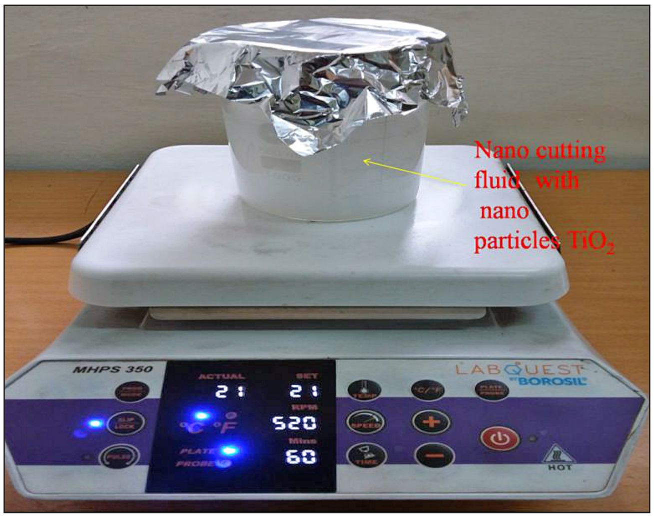

Fig. 1: Magnetic stirrer for nano-cutting fluid with nanoparticles TiO_2

Ultrasonification was performed by a water bath ultrasonicator. It was operated with single-phase electric supply at 200-230 Volts at 50Hz as depicted in Fig. 2. One litre distilled water was used for filing the water bath container. 30k Hz utrasonfication waves were generated. Initially, ultrasonification was performed for 30minutes. The rest of five minutes was given. Then it was repeated for five times. Visual inspection did not show any sedimentation. Zeta potential test was conducted. The value was 32 which was in a stable range.

Fig. 2: Water bath ultrasonicator

2.2.2 Nano-cutting fluid with Al_2O_3 nanoparticles

Nanoparticles of Al_2O_3 were weighed on micro digital balance with an accuracy of ±0.0001 grams. A sample of nano-cutting fluid was made with distilled water in the proportion weight of 1% (weight by weight) of distilled water. Magnetic stirring was done for blending of nano-cutting fluid for 60 minutes at 520 rpm at 21°C and rest was given for half an hour. This was repeated 4-5 times and the rest was given overnight for checking any sedimentation. Most of the surfactant used by previous researchers was sodium-based. Tween -20 Biocompatible surfactant has been found, which is non-toxic. Initially, 0.25% was mixed with nano-cutting fluid. Further, it was increased to 1% (weight by weight) of prepared nano-cutting fluid. Magnetic stirring was done at 520rpm at 21°C for 60 minutes. Then ultrasonication was done for 30 minutes and repeated 4-5 times. Zeta potential test was done and value was 21 which was in the stability range.

2.2.3 Conventional cutting fluid

The sample was prepared (w/w) in the ratio of 1:20. 1 part of conventional cutting oil and 20 parts of distilled water. This composition is used during machining processes like turning, milling, grinding, drilling etc.

2.2.4 Measurement of thermal conductivity

The thermal conductivity of different cutting fluids was measured by hot wire (KD2 thermal properties analyse, Decagon devices, Inc. USA). The experiment of measuring thermal conductivity of every cutting fluid was repeated five times and an average was calculated for finding out the final value.

2.3 Rheological property

Each sample was kept by a dropper at the cup and hob of Rheometer in the enclosed chamber. The temperature was adjusted at room temperature at 25°C and readings were noted for viscosity at the shear rate of 100/second for the time period of 125 seconds. The cup and hob were cleaned by acetone soaked paper. After leaving for drying for some time place another sample of nao-cutting fluid was placed and the chamber was closed and temperature was adjusted to 25°C another sample. Similarly, the samples of nano cutting fluids of Al_2O_3 TiO_2 and conventional cutting fluid were placed and analysed at 65°C.

3. Results and Discussion

3.1 Microstructural characterisation of nanoparticles

The characterization of nanoparticles Al_2O_3 was done by SEM and EDS images as shown in Fig. 2(a) and (b) at 100µm. Fig. 2 (b) shows high peaks of aluminium and oxygen. It was found that the percentage oxygen was more. The percentage of oxygen and aluminium in weight was depicted as 52.673% and 47.327% respectively.

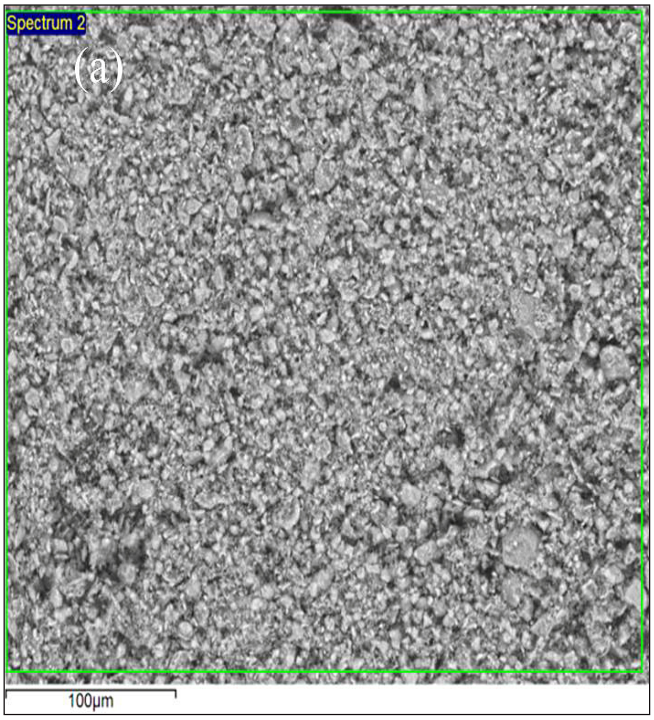

Fig.3(a): SEM image

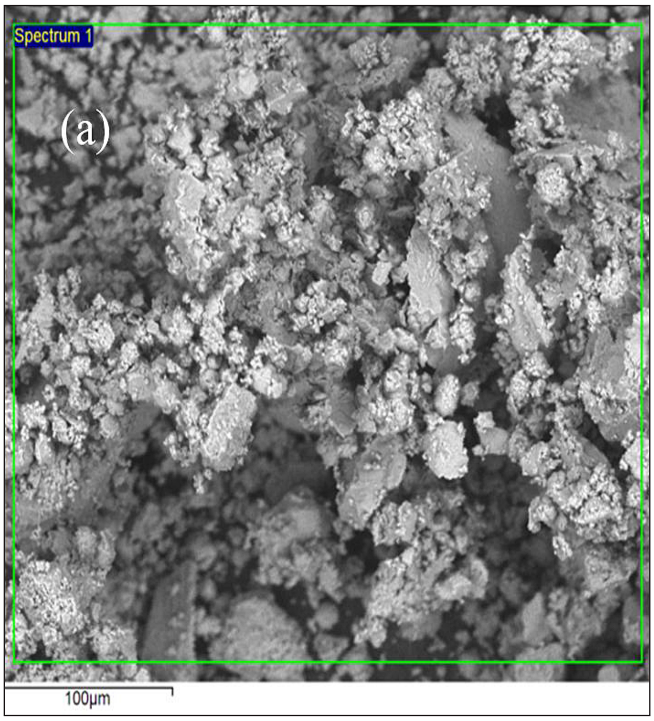

Fig.4(a): SEM image

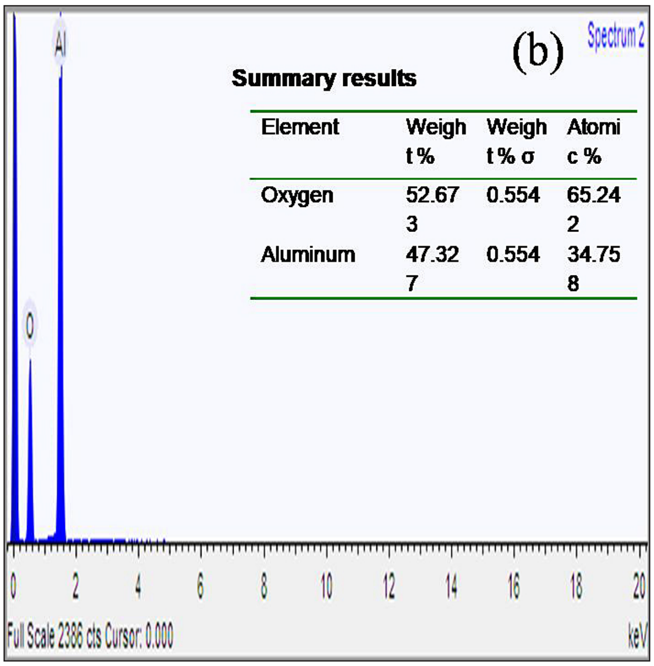

Fig.3(b): EDS of nanoparticles Al_2O_3

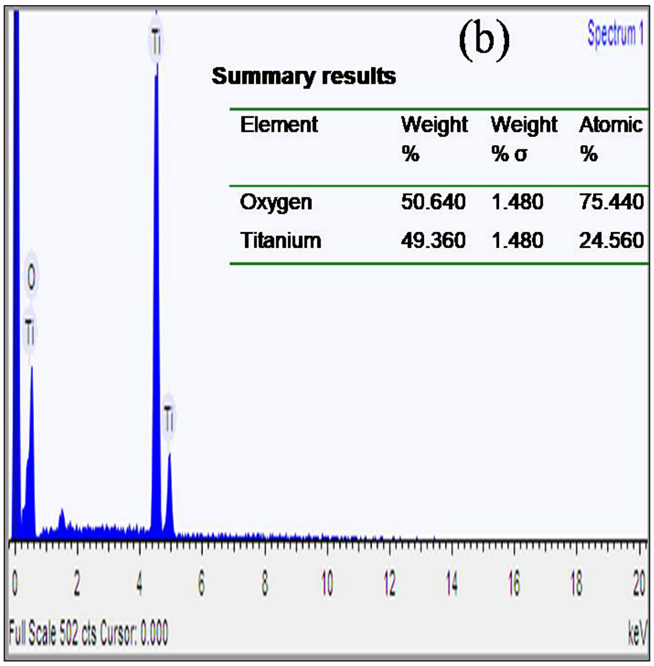

Fig.4(b): EDS of nanoparticles TiO_2

The characterization of nanoparticles TiO_2 was done by SEM and EDS images as shown in Fig. 4 (a) and (b) respectively with high peaks of titanium and oxygen. It has been shown that percentage of titanium was more. Comparatively, oxygen was progressively lower. The percentage of titanium and oxygen in weight as 49.360% and 50.640%.

3.2 Characterization of prepared nano-cutting fluids by TEM

Fig. 5 (a) shows TEM image at magnification of 40000 times and (b) shows TEM image at magnification of 60000 times of the prepared sample of nano-cutting fluid with nanoparticles of Al_2O_3. Some agglomerations of particles were seen.

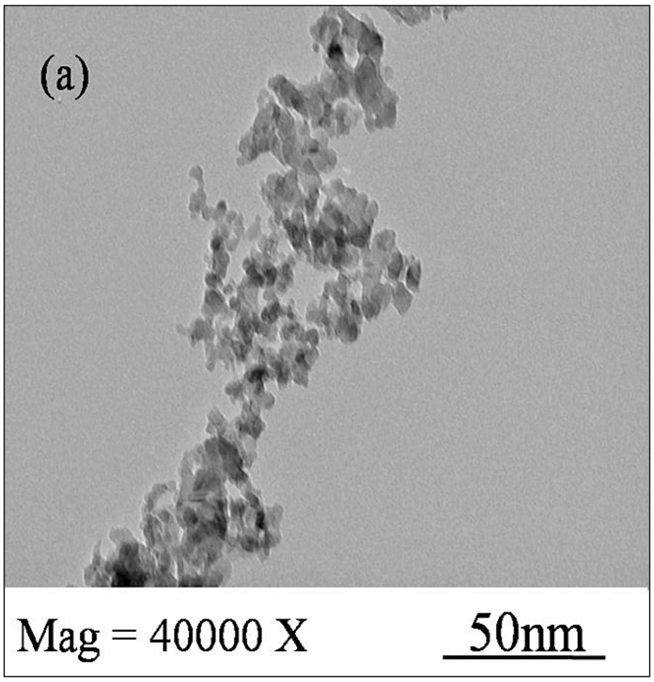

Fig.5(a): TEM image at magnification of 40000X

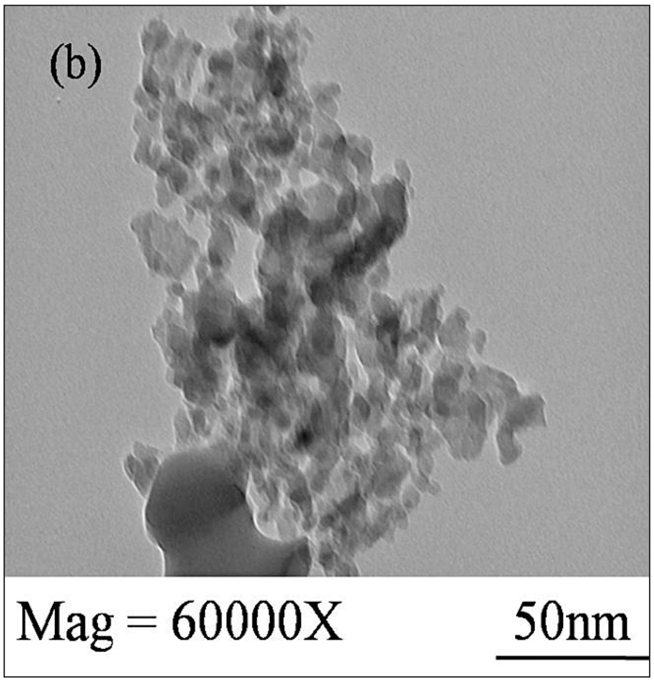

Fig.5(b): 60000X of prepared Al2O3 nano-cutting fluid

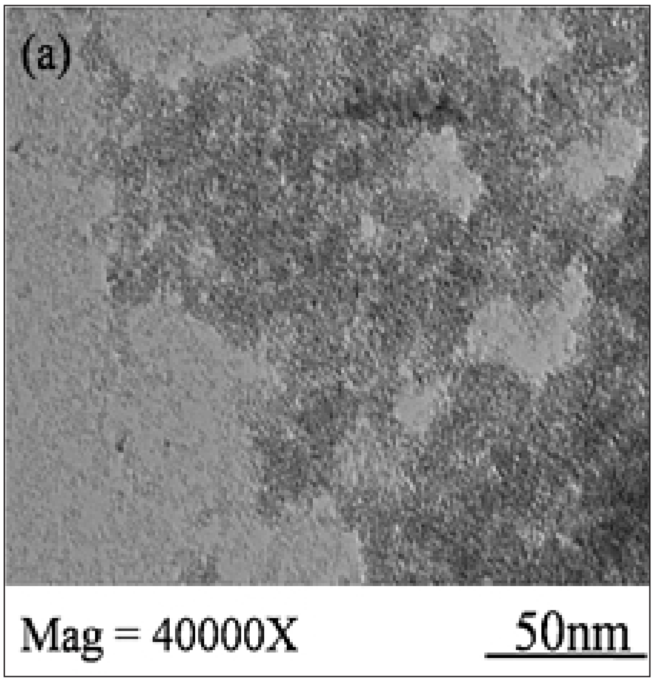

Fig.6(a): TEM image at magnification of 40000X

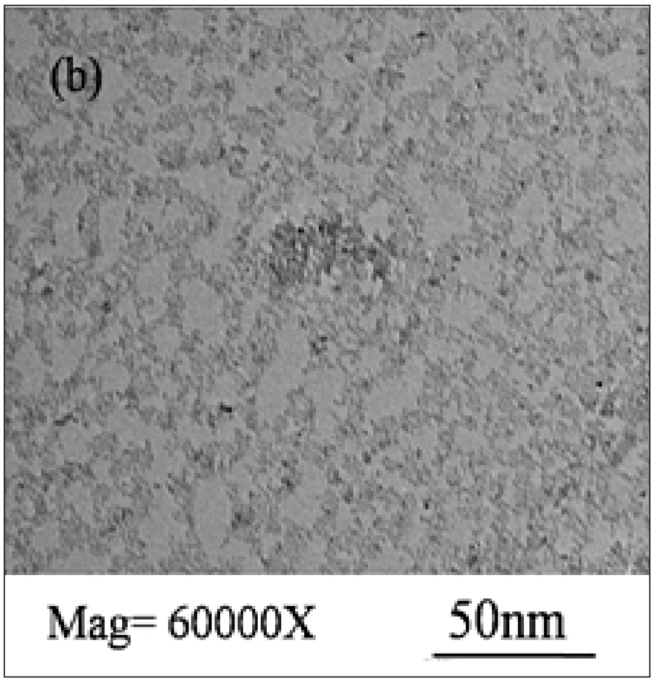

Fig.6(b): 60000X of prepared TiO_2 nano-cutting fluid

Characterization of prepared nano-cutting fluids by performing TEM image of samples Figure 6 (a) shows TEM image at a magnification of 40000 times and (b) shows TEM image at a magnification of 60000 times of the prepared sample of nano-cutting fluid with nanoparticles of TiO_2. It has been seen that particle size was very fine and no agglomeration of particles was seen.

3.3 Characterization of prepared nano-cutting fluids by Raman Shift

It has been shown in Fig. 7 that highest peak of Al_2O_3 was observed at 1100-1200 Raman shift/cm^{-1} for 380 counts. This confirmed the presence of Al_2O_3. Another peak was observed at 2200-2300 Raman shift/cm^{-1} for 100 counts.

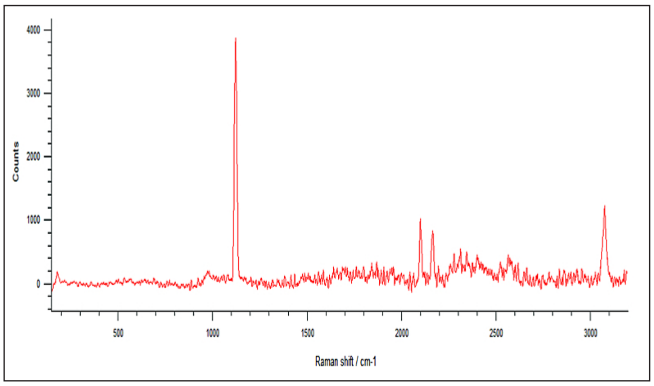

Fig.7: Raman shift pattern for Al_2O_3 in prepared nano-cutting fluid

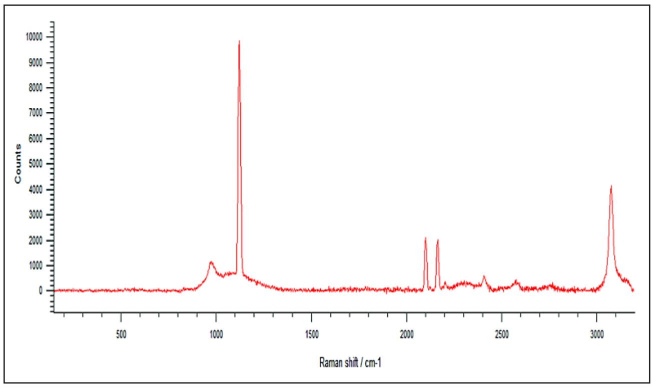

Fig.8: Raman shift pattern for TiO_2 in prepared nano-cutting fluid

Fig. 8 depicts that the highest peak was observed at 1200-1300 Raman shift/cm^{-1} for 980 counts. This confirmed the presence of TiO_2 in the prepared nano-cutting fluid. Another high peak was observed at 3200-3300 Raman shift/cm^{-1} for 450 counts.

3.4 Rheological property of nano-cutting fluids

It has been depicted in Fig. 9 that at the initial start of rheometer till first 20 seconds the viscosities of AA, TT and CC was higher than respective viscosities at the end of 125 seconds at the shear rate of 100/seconds at 25°C. On comparing the viscosity of nano-cutting fluids AA, TT with CC it was found that viscosity was declined by 91.92 and 90.81% respectively at the viscosity obtained at the end of 125 seconds. In Fig. 10, it was found that viscosities declined at the end of 125 seconds. On comparing the viscosity of nano-cutting fluids AA, TT with CC it was found that viscosity was declined by 94.02 and 86.19% respectively at the velocity obtained the end of 125 seconds at 65°C. On comparing both the Figs. 9 and 10 it was found that respective viscosity of nano-cuting fluids and cutting fluid were lower at higher temperature at 65°C due to weaker intermolecular forces.

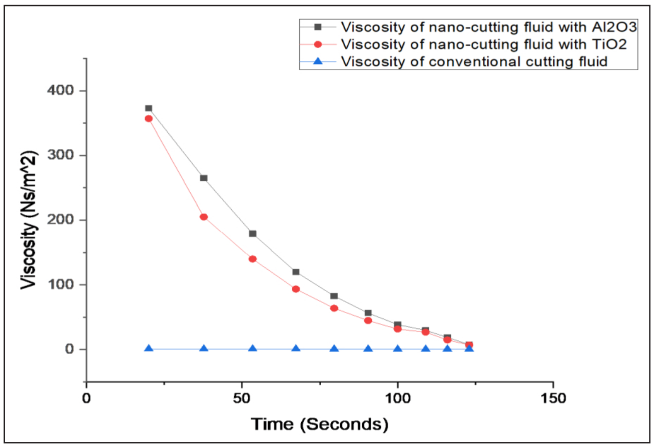

Fig.9: Visocity of cutting fluids with time at room temperature 25°C

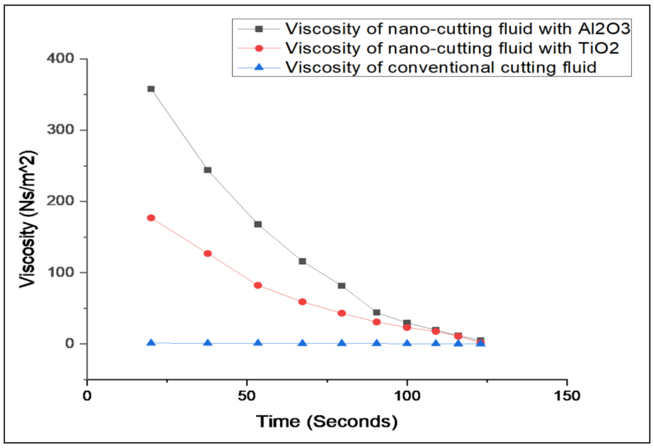

Fig.10: Viscosity of cutting fluids with time at 65°C

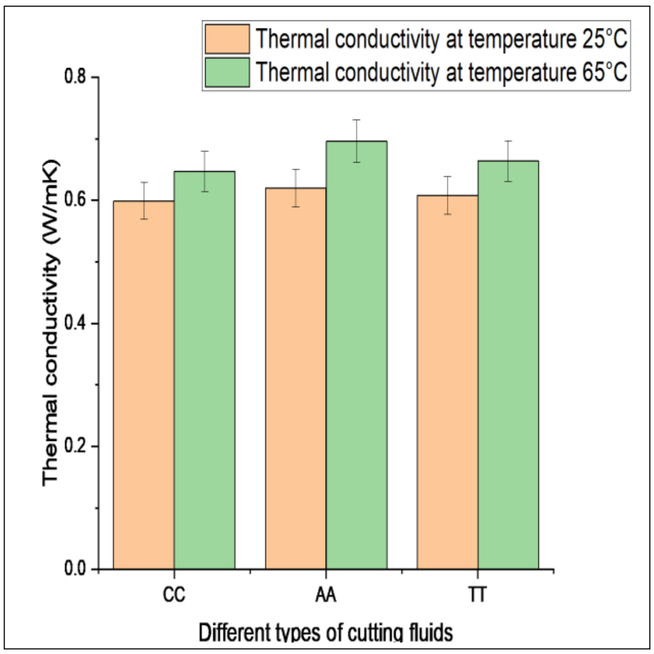

Fig.11: Thermal conductivity of nano-cutting fluids and conventional cutting fluids

3.5 Thermal conductivities of cutting fluids

The thermal conductivity of cutting fluids was found to be more at higher temperature of 65°C on comparing with temperature of 25°C as depicted in Fig. 10. The thermal conductivity was enhanced by 7.42, 10.91 and 8.42 % respectively for CC, AA and TT at higher temperature of 65°C. The inclination in thermal conductivity was higher for nano-cutting fluid with Al_2O_3 due to the property of material.

4. Conclusions

The nano-cutting fluids were prepared from two distinct nanoparticles and after characterization the samples were tested for change in viscosities on a dedicated rheometer. The following conclusions were summarized:

1 Biocompatible surfactant was used during the preparation of nano-cutting fluid with Al_2O_3.
2 The temperature influenced the viscosity of prepared nano-cutting fluids.
3 The viscosity of nano-cutting fluids and conventional cutting fluids declined with the increasing time period at shear rate of 100/second.
4 The viscosity of nano-cutting fluids and cutting fluids declined with increasing temperature.
5 The nano-cutting fluid with Al_2O_3 depicted more stability in viscosity change.
6 The thermal conductivities increased during higher temperature.

Abbreviations

w/w: Weight by weight
AA: Nano-cutting fluid with Al_2O_3
TT: Nano-cutting fluid with TiO_2
CC: Conventional cutting fluid (1:20)

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