Preparation and characterization of nanoparticles mixed cutting fluids

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Abstract

Health and environmental concerns about the use of excessive conventional cutting fluids during conventional machining has led to the development of a new type of cutting fluid. Inefficient disposal of industrial cutting fluids during wet machining also reduces the use of conventional cutting fluid. Nano-material mixed cutting fluids have shown superior thermal properties and tribological properties. In the present work, different nanofluids are prepared by suspension of Titanium dioxide (TiO_2), Silicon oxide (SiO_2) and Aluminum oxide (Al_2O_3) nanoparticles in vegetable oil and water-based emulsion at room temperature in different volumetric concentrations. The viscosity and density of the developed nanofluids are measured at different temperatures for different nanoparticle volumetric concentrations. From the experimental results, it has been found that with the increase of nanoparticle concentration in base fluid, enhanced the its viscosity and density. Furthermore, addition of nanoparticles at 25 ºC enhances viscosity more compared to its addition at higher temperatures. For an increase of concentration from 0.25% to 3%, enhancement in viscosity of Al_2O_3, SiO_2 and TiO_2 nanofluids is observed as 41.6%, 43.75% and 35.55%, respectively, while for higher temperatures almost constant improvement of 25%, 24% and 30% is observed for Al_2O_3, SiO_2 and TiO_2 nanofluids, respectively. The viscosity and density of three different nanofluids are also compared. Results showed that newly prepared Al_2O_3 based nanofluid exhibits better properties than TiO_2 and SiO_2 based nanofluids. Copyright © 2017 VBRI Press.

Keywords: TiO_2, SiO_2, Al_2O_3, viscosity, density.

Introduction

Machining of low strength materials is easy as compared to high strength materials due generation of less heat, which leads to rise in temperature at machining zone but this rise in temperature do not pose a serious problem. However, machining of high strength alloys, high cutting temperature at high speed lowers the strength of the tool, which increases the tool wear rate. Although, in the industries high speed machining is preferred to increase the production, which leads to faster tool wear rate and restricts the increase of cutting speed up to a certain limit. The long use of cutting tools at high speed generated excessive heat at cutting tool, which reduced the sharpness of cutting tool edge. Machining with the use of a blunt tool consumes more power and produces a lower surface finish. Therefore, use of cutting tools within the desirable limits and conditions, the produced heat at workpiece-tool-chip interfaces needs to be extracted continuously. Cutting fluid is applied during the machining zone to reduce these problems.

Astakhov and Joksch [**1**] discussed in detail the historical development of cutting fluids in his research and noticed that water is the most commercial and cheaply available universal cutting fluid due to its better thermal conductivity. Furthermore, in some of the machining process observed that use of water as coolant restricts its application due to poor lubricating property and the formation of corrosion. To overcome these problems gives motivation to researchers to develop new type of cutting fluids which replace the water as cutting fluid. Researchers developed the oil-water emulsion which shows better lubrication and cooling properties. Mixing of vegetable oil and mineral oils in water improved the lubrication characteristics. Few researchers have mixed the nanometer-sized solid particles of metallic, nonmetallic, and ceramics into conventional cutting fluid called "nanofluids" to improve their thermo physical properties. Nanofluids have better stability, higher thermal conductivity and excellent cooling and lubrication properties compared to the conventional cutting fluid.

Nanofluids are the mixture of nanometer-sized metallic, non-metallic, CNT, oxides solid particles and even nano-scale liquid droplets in a low viscosity base fluid. Choi [**2**] (Energy Technology Division, Argonne National Laboratory, USA) coined the term "nanofluid" first time in 1995. Murshed *et al.* [**3**], Ettefaghi *et al.* [**4**], Wang *et al.* [**5**], Qiang *et al.* [**6**] Noticed in their investigation that an increase of thermal conductivity upon addition of nanoparticles into base fluid. Few researchers [**7-9**] have reported in their investigations that increase of nanoparticles volumetric concentration in conventional fluids enhanced their thermal conductivity compared to base fluids.

Mariano *et al.* [**10**] investigated the thermo-physical properties of Co_3O_4 ethylene glycol-based nanofluid. Viscosities of the nanofluid with different concentrations were increases with increase in the concentration of nanoparticles and decreases with temperature. The density of nanofluids behaves in the same nature as it increases with pressure and decreases with temperature. Lee *et al.* [**11**] experimentally studied the thermal conductivity and viscosity of Al_2O_3 nanoparticles mixed cutting fluid with different concentrations. The viscosities of water-based Al_2O_3 nanofluids decreases with increase in temperature and nonlinear relationship observed between viscosity and nanoparticles concentrations. Sundar *et al.* [**12**] studied experimentally thermal conductivity and viscosity of mixture of nanodiamond-nickel nano-composite into water. Results showed that maximum increase in the viscosity was recorded at 3.03 wt. % of nanoparticles compared to water. Li *et al.* [**13**] investigated the thermal conductivity and viscosity of mixture of ethylene glycol and ZnO at different concentrations. From the results, less than nanofluid with 10.5 wt. % ZnO shows newtonian behavior and viscosity decreases with increase in temperature and increases with the increase in mass fraction of nanoparticles. Namburu *et al.* [**14**] experimentally studied the viscosity and specific heat of SiO_2 nanoparticles mixed cutting fluid at various concentrations. At lower temperature SiO_2 nanofluid exhibits non-newtonian behavior and viscosity of the nanofluid increases with increase in the volumetric concentrations while decreases with increase in temperature. Shoghl *et al.* [**15**], Yu *et al*. [**16, 17**], Murshed *et al.* [**18**] and Turgut *et al.* [**19**] experimentally studied the thermal conductivity and viscosity of ceramic nanoparticles mixed nanofluids. The results showed that viscosity of the nanofluid increases with increase in concentration of nanoparticles concentration. Jeong *et al.* [**20**] investigated the influence of shape of the nanoparticles on viscosity and thermal conductivity of ZnO nanofluid. Results showed that the viscosity and thermal conductivity of nanofluid increases with increase in the concentration of nanoparticles and rectangular shape of the nanoparticles have greater effect on viscosity and thermal conductivity. Phuoc *et al.* [**21**] experimentally investigated the viscosity and thermal conductivity of CNT-based nanofluid. The thermal conductivity and viscosity of the CNT-based nanofluid enhanced with increase in the concentration of CNT. Sundar *et al.* [**22**] investigated the viscosity of low nanoparticles concentrations in different base fluids. The nanoparticles were added with various concentrations into three different ratios of water and ethylene glycol mixed based fluid at different temperatures. **Fig. 1** showed that viscosity of nanofluid increases with increase in temperature while decreases with temperature.

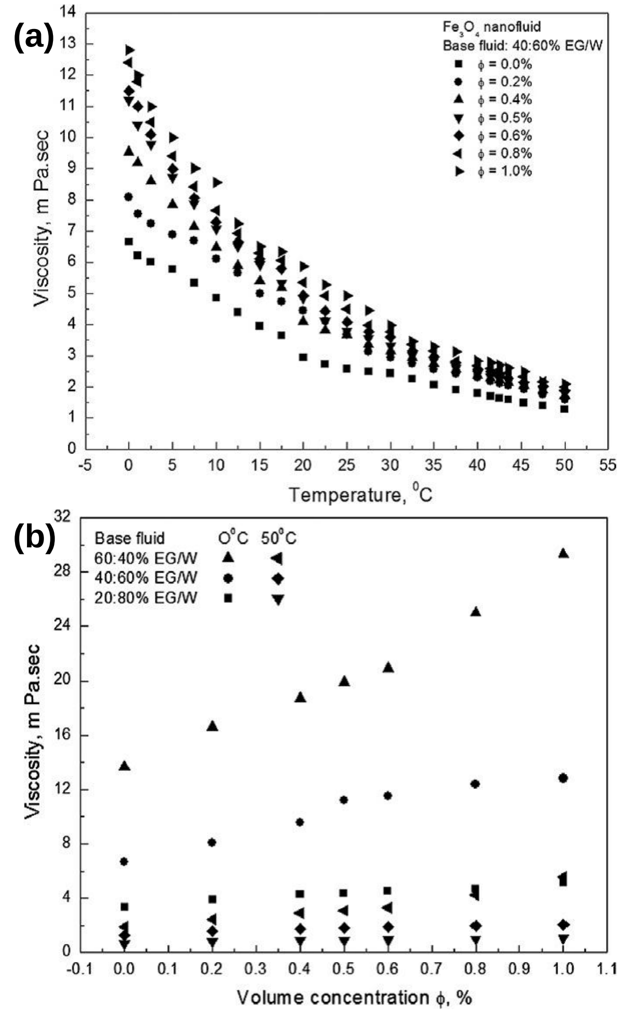

Fig. 1. Variation of viscosity at (a) with temperature at various nanoparticles concentration (b) with nanoparticles concentrations at different EG/W base fluid ratios [**22**].

There are so many researchers published their work in the field of nanofluids. Tiwari *et al.* [**23**] reported the variation of thermal conductivity and dynamic viscosity on the basis of available literature. The viscosity ratio of nanofluid to base fluid increases with increase in the concentration of nanoparticles and furthermore, shape of the nanoparticles also affects the viscosity and thermal conductivity of nanofluids. Sharma *et al.* [**24, 25**] reviewed the research work of many researchers in the field of nano cutting fluid and found that addition of nanoparticles into base fluid enhances its thermal conductivity, which in turn, improves surface quality, tool life and reduces the cutting force and cutting temperature, when applied as cutting fluid in machining.

In the present work, three special types of nanocutting fluids are prepared by adding Al_2O_3, TiO_2 and SiO_2 nanoparticles to vegetable oil and water emulsion (5% vol. oil in water) in various proportions like 0.25%, 0.5%, 1.0%, 1.5 %, 2% and 3 % vol. After preparation, the nanofluid is characterized for its viscosity and density at different temperatures and concentrations. Later, the effect of temperature and volumetric concentration on the above-mentioned properties was analysed for all three nanofluids.

Experimental

In the present experimentation three commercially available colloidal suspensions containing Aluminum oxide (Al_2O_3), Nano Tek® AL-6050, 23% in water, 45 nm in diameter; Titanium Oxide (TiO_2), 35% in water, 25 nm in diameter and Silicon Oxide (SiO_2), 30% in water, 10 nm in diameter were obtained from Alfa Aesar®. Before starting the experiment, different nanoparticles concentrations were added into base fluid to develop the mixture of nano-enriched cutting fluids. Different concentrations such as 0.25, 0.5, 1.0, 1.5, 2.0 and 3 vol. % were used in this study. To get the uniform mixing and stable suspension, the nano-enriched cutting fluids were kept under ultrasonic vibration continuously for 6 h. To dissolved and slow down the agglomeration of the nanoparticles in base fluid ultrasonic vibrator (Toshiba, India) generating ultrasonic pulses of 100W at 36±3 kHz and magnetic stirrer were used. The purchased nanofluid at definite concentration the surfactant was done by supplier. To achieve the uniform stability of nanofluid proper mechanical mixing and ultrasonic sonication is needed. Also to prevent possible sedimentation/ agglomeration, for each test a new nanofluid had been prepared freshly and immediately used.

For the measurement of viscosity of different nano-enriched cutting fluids LVDV-II+Pro Brookfield digital viscometer (cone and plate) was used. The instrument have computer controlled temperature bath to record the viscosity at different nanofluids at different temperatures. The viscometer allows changes in rotational speed such as torque ranges can be attained for differing viscosities. Most of the times, low viscosity nano-enriched cutting fluids require spindles with larger surface area and at high rotational speeds. The cone is connected with the spindle and plate is mounted on the sample cup. CPE42, spindle was used to measure the viscosities of samples staring from 0.3cP. The minimum quantity of nanofluid sample required for measurement of viscosity is 1 ml. The rotation of spindle produces the viscous drag force against the spindle and this drag force is measured by the deflection of the calibrated spring. The combination of spindle type and speed combination will produce the results by applying the torque between 10% to 100% of the maximum permissible torque. So make sure during measurement that the applied torque is out of this specified range. Before starting the measurement, the viscometer was benchmarked with distilled water, glycerine and ethylene glycol at room temperature. The density of the nanofluids at different concentration was measured by taking the weight of 1lt. nanofluid. The density of the nanofluid is calculated by physical relation between mass and volume. The uncertainty of the measurement is less than 2%. To minimize the measurement errors, during experiments each experiment was measured four-five times per sample. The measurement data used in this work is represents the average of the four-five values.

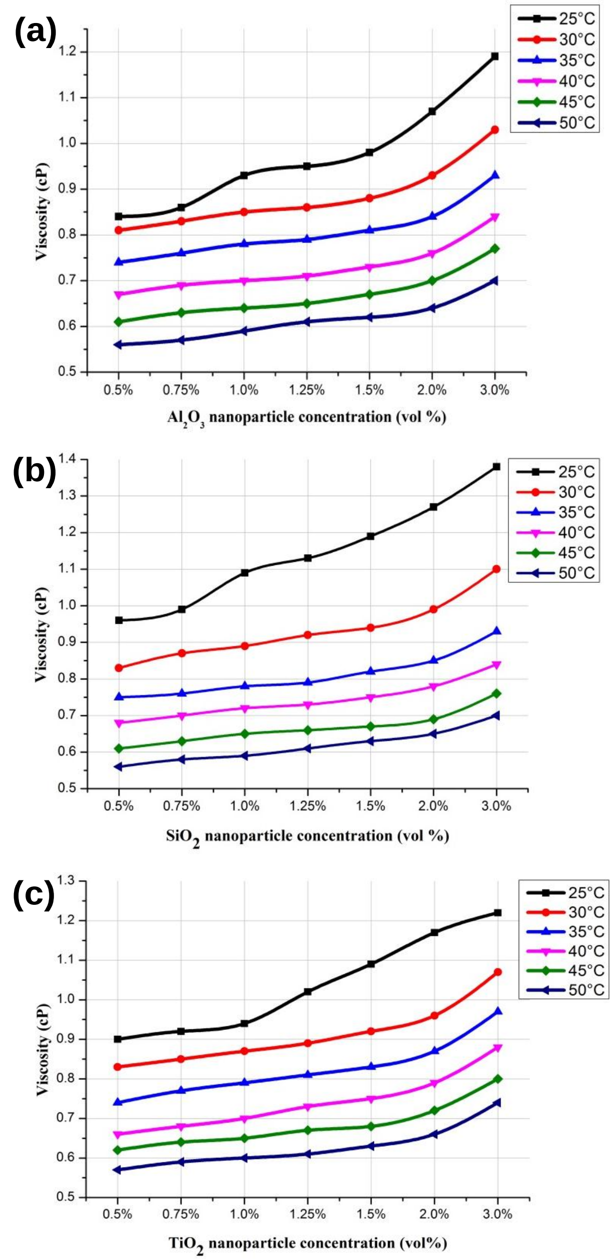

Fig. 2. Viscosity of (a) Al_2O_3 (b) SiO_2 (c) TiO_2 based nanofluids on different nanoparticles concentrations with a variation of temperatures.

Results and discussion

Viscosity of all the three nanofluids with different fractions is measured. The average of four-five values was taken to represent the viscosity at different fractions and temperatures. **Fig. 2** shows the variation of viscosity of Al_2O_3 mixed nanofluid, SiO_2 mixed nanofluid and TiO_2 mixed nanofluid with different nanoparticle concentration and temperatures. Result showed that all three nanofluids viscosity is found to be increased by increasing the nanoparticles concentrations in conventional cutting fluid. **Fig. 2** showed that TiO_2 mixed nanofluid exhibits highest viscosity while Al_2O_3 nanofluid exhibits lowest viscosity for all the concentrations among three nanofluids at 50 ºC.

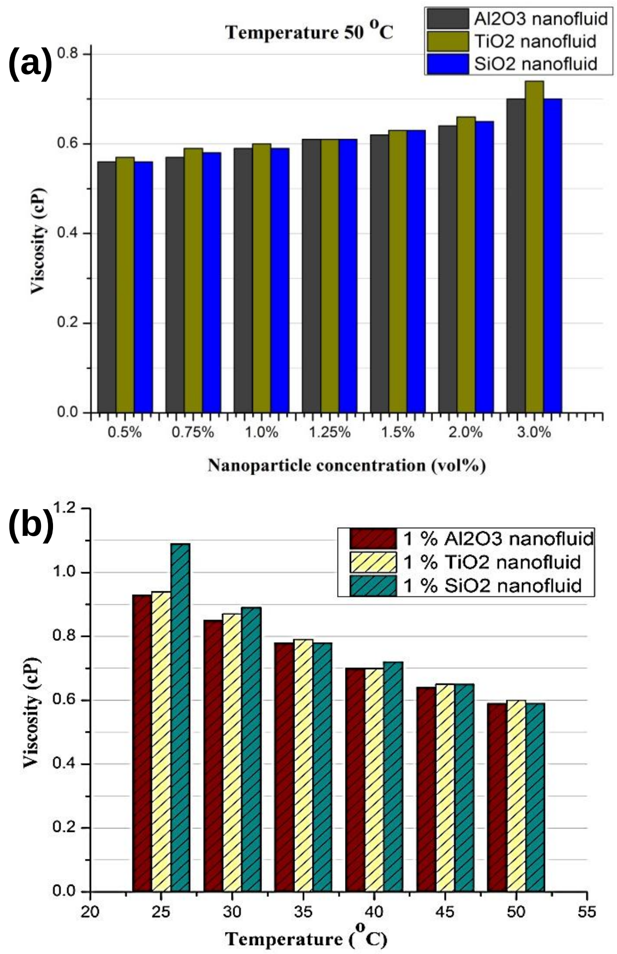

Fig. 3. Viscosity of all three nanofluids at (a) at different nanoparticles concentrations (b) at different temperatures.

Higher viscosity nanofluid requires more pumping power. Low viscosity cutting fluid is preferred in machining, so use of Al_2O_3 nano-enriched cutting fluid may be a better choice among all three for experimentations. **Fig. 3** shows the comparative variation of all three nanofluids with different nanoparticles concentrations such as 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3.0 % at different temperatures: 25, 30, 35, 40, 45 and 50 ºC. It has been found that Al_2O_3 nanofluid recorded minimum value of viscosity, which makes it useful as cutting fluid during machining. At lowest temperature (25 ºC), highest improvement in viscosity was recorded due to increase of concentration from 0.25% to 3%. The recorded improvements in all three nanofluids were as 41.6%, 43.75% and 35.55% for Al_2O_3, SiO_2 and TiO_2 nanofluids respectively. At higher temperatures almost constant improvement of 25%, 24% and 30% were recorded for Al_2O_3, SiO_2 and TiO_2 nanofluids, respectively. **Fig 4** showed the variation of density of all the three nanofluids with respect to nanoparticles volumetric concentration at 25ºC temperature. It can be observed from the graph that density of all three nanofluids increases with increase of nanoparticle fractions. It has been observed from the graph that TiO_2 nanofluid exhibits highest density and SiO_2 nanofluid has the lowest density among all three types of nanofluids. When nanoparticle concentration increases from 0.25vol. % to 3 vol.%, enhancement of 5.57%, 3.59% and 7.84% is achieved in density of Al_2O_3, SiO_2 and TiO_2 nanofluids, respectively.

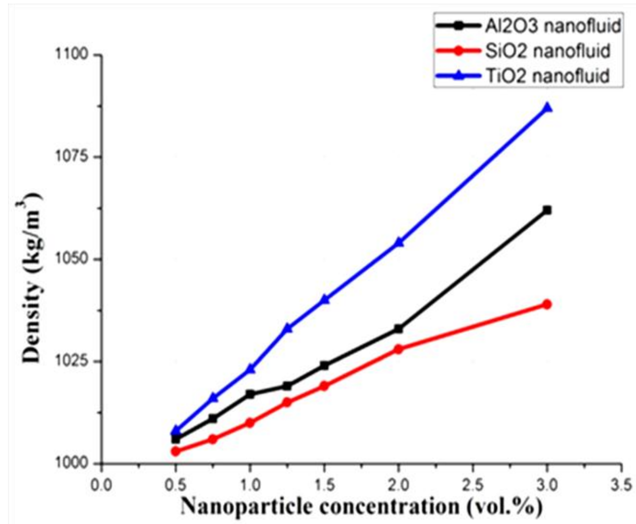

Fig. 4. Comparative variations of density of Al_2O_3, TiO_2 and SiO_2 nanofluids with nanoparticles concentrations.

Conclusion

Three different types of nano-enriched cutting fluids are developed by suspension of Al_2O_3, TiO_2 and SiO_2 nanoparticles to emulsion of (mixture of vegetable oil and water with 5% vol. Oil in water) at different volumetric concentrations such as 0%, 0.25%, 0.5%, 1.0 %, 1.5 %, 2% and 3 % vol. The developed nanofluids are characterized for its rheological, thermo-physical and tribological properties at different temperatures: 25, 30, 35, 40, 45 and 50 ºC and different concentrations. From the experimental study, there are few conclusions have been drawn:

- The viscosity of all three nanofluids increases with increase of nanoparticles concentrations at all temperatures.
- Addition of Al_2O_3 nanofluid shows lower viscosity compared to TiO_2 and SiO_2 nanofluids.
- At room temperature, the viscosity of the nanofluids increases with increase in nanoparticles concentrations.
- From the results 41.6%, 43.75% and 35.55% enhancement in viscosity of Al_2O_3, TiO_2 and SiO_2 nanofluids respectively recorded while at higher temperatures, minute improvement of 25%, 24% and 30% is observed for Al_2O_3, SiO_2 and TiO_2 nanofluids, respectively.

- The density of Al_2O_3, SiO_2 and TiO_2 nanofluids increases with increase in the nanoparticles concentrations.

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