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Stability analysis of hybrid Al_2O_3-TiO_2 nano-cutting fluids

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ABSTRACT

Purpose: This paper is to study the stability of the current combination of hybrid nano-cutting fluids due to the recent progress in the analysis of nano-cutting fluids, such as the assessment methods for the stability of nano-cutting fluids, have revealed that instability is a common problem associated with nano cutting fluids.

Design/methodology/approach: Five samples of 0.001 vol% that are suitable to be tested at UV-Vis machine, Al_2O_3–TiO_2 hybrid nano-cutting fluid was prepared using a one-step process with the help of a magnetic stirrer to stir for 30 minutes with different sonication time to determine the best or optimum sonication time for this hybrid nano-cutting fluid. Stability of nano-cutting fluids was analyses using UV–Vis spectrophotometer (0.001%, 0.0001%, 0.00001%), visual sedimentation (1%, 2%, 3%, 4%), TEM photograph capturing techniques (2%) and zeta potential analysis (0.001%, 0.00001%), that used different volume concentration that is suitable for each type of stability analysis.

Findings: The stability analysis reveals that the best sonication time is 90 minutes, and the UV-vis spectrophotometer shows the stability of all samples is above 80% during a month compared to the initial value. Further, visual sedimentation shows good stability with minimum sedimentation and colour separation only. The zeta potential value also shows great stability with a value of 37.6 mV. It is found that the hybrid nano-cutting fluid is stable for more than a month when the nano is suspended in the base fluid of conventional coolant.

Research limitations/implications: The result in this paper is based on the experimental study of Al_2O_3-TiO_2/CNC coolant base hybrid nano-cutting fluid for a month. However, to further validate the results presented in this paper, it is recommended to prolong the stability assessment time for six months for longer shelf life.

Practical implications: The finding of this experimental study can be useful for high-precision product machining using similar CNC coolants, especially for aircraft and airspace applications for machining parts.

Originality/value: No thorough stability assessment using all four types of stability analysis is done on Al_2O_3-TiO_2/CNC Coolant base hybrid nano cutting fluid.

Keywords: Al_2O_3-TiO_2, Nano cutting fluid, Hybrid nano, Stability analysis

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PROPERTIES

1. Introduction

Cutting fluid cools and lubricates the tool-workpiece contact while eliminating chips from the cutting zone during metal cutting operations [1]. As a result, the tribological conditions at these surfaces may be dramatically affected by a cutting fluid. Excessive usage of conventional cutting fluid, on the other hand, harms both human health and the environment. As a result, a new class of cutting fluid with excellent thermal and tribological qualities has been developed to limit its excessive use during the cutting process [2]. Agrawal and Patil [3] stated cutting process using a typical flood lubrication system is a common technique in the manufacturing industries for decreasing friction, heat, and cutting power, according to a discussion on the problem of flood lubrication and factors impacting machining performance. If and only if the type of cutting fluid used during machining is properly selected, applied, handled, and disposed of, it can significantly improve machining performance. The temperature during certain machining processes needs to be controlled so that the finished part is of good quality [4]. The turning process is one of the most common processes in machining, which will determine the quality of the process by checking the surface roughness value of the machined part [5]. One of the aspects that must be studied to obtain maximum or optimum machining performance is the cutting fluid's stability, and current research is focused on generating a better and more sophisticated cutting fluid, which is nano-cutting fluid.

According to Mukesh Kumar et al. [6], nanofluids are new heat transfer fluids that consist of nanoparticle dispersion in a base fluid. Nanofluids are widely used in many studies and applied to various products such as solar collectors [7]. Past researchers have studied mono and hybrid nanofluid combinations [8]. Nanofluid instability is a prevalent problem related to nanofluids, and recent work on the study of nanofluids, such as the evaluation methodologies for nanofluid stability, has been made. A UV-Vis spectrophotometer and visual sedimentation are two methods for determining the level of stability of nanofluids. Redhwan et al. [9] assessed the stability of nanofluids; the researcher used both qualitative and quantitative approaches, starting with sedimentation image collecting methods for two weeks and then validating the qualitative results with a UV-Vis spectrophotometer. Sharif et al. [10] highly suggest a four-step UV-Vis spectral absorbency method to analyse the stability of the nanofluid in which SiO_2 nanomaterials were dissolved in the PAG lubricant by using the two-step process, and the nanofluid was deemed stable if the precise value was over 70% compared to the initial absorbance even after 30 days. Othman et al. [11] employed quantitative and qualitative data-gathering approaches, including the UV-spectrophotometer and observation of sedimentation using the traditional method, to explore nanoparticle stability in liquid phase conditions.

Aside from that, other tests, such as Zeta potential analysis and TEM analysis, can be used to determine the level of stability of nano-cutting fluids. Gulzar et al. [12] employed TEM and Zeta analysis in their studies. Zeta potential (ZP) measurements use a universe and data of all hybrid nanofluid samples obtained after 3 hours, 72 hours, and seven days of production. While TEM images were taken at 200 nm and 100 nm, respectively. Shuang et al. [13] TEM images were used to capture the size of graphene oxide nanofluids, and the images were taken at a resolution of 50 nm. Singh et al. [14], to justify the size of nanoparticles present in the colloidal suspension at 2 um, 100 nm, and 50 nm, a TEM image was also taken.

Zeta potential (ZP) measurements were performed using the universe to determine whether the hybrid nanofluid samples have stable ZP values before proceeding to the next research stage, machining using hybrid nano-cutting fluid. This Zeta potential (ZP) value is used to determine the stability level of a nanofluid; if the ZP value is below 30 mV, the nano-cutting fluid is considered unstable; if the ZP value is higher than 30 mV, the nano-cutting fluid is considered stable [12].

Al_2O_3-TiO_2/Therminol-55 hybrid nanofluid was prepared for solar collectors' purposes, and the stability analysis was done using visual sedimentation and zeta potential value measurement [12]. However, none of the researchers prepared Al_2O_3-TiO_2/CNC coolant for machining purposes and tested the stability of Al_2O_3-TiO_2/CNC coolant hybrid nano-cutting fluid in four different types of stability tests.

The main research question is whether the current hybrid combination does have good stability before being used in the machining area. Hence, the gaps in this study and past research are the type of hybrid used and multiple stability testing. The novelty is from the combination of nanofluid with the CNC coolant as the fluid based.

Al_2O_3-TiO_2/CNC coolant hybrid nano-cutting fluid was prepared using a one-step process, and the stability was assessed using a UV-Vis spectrophotometer, visual sedimentation, zeta potential analysis, and TEM photography.

2. Methodology

In this investigation, Al_2O_3 and TiO_2 metal oxide nanoparticles are taken as nanomaterials, and distilled water and coolant oil are taken as base fluid. The mixing ratio for the base fluid is 95:5. (distilled water: coolant oil). The Al_2O_3-TiO_2 hybrid nanofluid is made using a one-step technique [15]. This is because the one-step approach is superior for oxide particles, providing greater stability and reducing agglomeration [16]. Dissolving Al_2O_3 and TiO_2 nanoparticles in the base liquid for 30 minutes using the mixing method dilutes the Al_2O_3-TiO_2 hybrids nanofluid [15]. The nanoparticles of alumina (Al_2O_3) and titanium (TiO_2) employed in this work are liquid. Al_2O_3 has a primary particle size of 30 nm, whereas TiO_2 has a primary particle size of 30-50 nm. The average size of Al_2O_3-TiO_2 nanoparticles was validated via TEM examination, as shown in Figure 1. Since TiO_2 nanoparticles are larger than Al_2O_3 nanoparticles, Al_2O_3 nanoparticles fill the space between the TiO_2 nanoparticles. Combining two nanoparticles of different sizes would reduce the gap between smaller and larger particles, enhancing thermal properties such as dynamic viscosity and heat transmission capabilities.

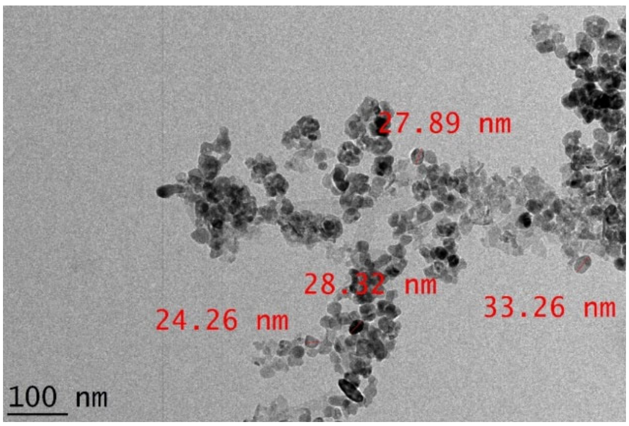

Fig. 1. TEM analysis of 28.43 nm average size of Al_2O_3-TiO_2 nanoparticles

Apart from that, the TEM analysis is used to view the dispersion of hybrid nanoparticles in liquid form using advanced microscopes brand FEI Tecnai F20 200 kV, hence confirming its stability. Figure 1 clearly shows that both Al_2O_3 and TiO_2 nanoparticles were well dispersed, and agglomeration is not occurred after being dispersed into the based fluid of CNC coolant. This is reflected stability of this Al_2O_3-TiO_2 hybrid nano cutting fluid, and the combination of this hybrid nano-cutting fluid will provide a long shelf life.

In general, the properties of Al_2O_3 and TiO_2 nanoparticles are shown in Table 1, with the form of nanoparticles used being liquid and the weight concentrations of Al_2O_3 and TiO_2 being 20 wt.% and 40 wt.%, respectively, as well as the density of nanoparticles used during the formulation and dilution of nano cutting fluid. The base fluid is a blend of distilled water and cooling oil (Beiling X-Ten), which is specifically intended for use in cutting fluid applications for CNC machining. Table 2 lists the parameters of the base fluid. The density of cooling oil is estimated to be between 700 and 950 kg/m^3, while distilled water has a density of 1000 kg/m^3. Beiling X-Ten 150 coolant oil was utilised, and the distilled water was made in the laboratory rather than purchased. The properties of these nanoparticles and based fluid are needed for reference, especially for volume concentration calculation purposes. Tables 1 and 2 summarise the nanoparticle's and base fluid properties, respectively.

Table 1.
Properties Al_2O_3 and TiO_2 nanoparticles

Property	Aluminium oxide	Titanium oxide
Molecular Formula	Al_2O_3	TiO_2
Form	Liquid	Liquid
Diameter	30 nm	30-50 nm
Weight Concentration	20 wt%	40 wt%
Density	4000 kg/m^3	4230 kg/m^3

Table 2.
Properties of base fluid

Property	Coolant Oil	Distilled Water
Density	700-950 kg/m^3	1000 kg/m^3
Brand	Beiling X-Ten 150	(from laboratory)

In a variety of chemicals measuring cylinders, the needed particle volume concentration is calculated with an accuracy of 1.0 ml and 0.5 ml. When particles are dispersed in water, ultrasonication is perhaps the most effective method for breaking up agglomeration and ensuring equal dispersion. To achieve equal distribution, breakdown down agglomeration, and create a steady suspension, the nanofluids are vibrated continuously for 1.5 hours [17]. To achieve uniform dispersion and stable suspension, an ultrasonic bath (Branson, Mexico) emitting Ultrasonic pulses of 110 W at 406 kHz was turned on for 1.5 hours.

The stability of nanoparticles distributed in base fluids was quantified using UV-Vis spectrophotometer (UV-Vis) measurements. Because light intensity fluctuates as it goes past a fluid due to absorption and scattering, the UV-Vis spectrophotometer took advantage of this. A UV-Vis. spectrometer, UV-1800 model, Shimadzu make, with an absorption wavelength of 849-851 nm, was used to test the stability of nanofluid, with data taken at 850 nm as demonstrated by [18].

3. Results and discussions

3.1. Best sonication time

A sample of 0.001 vol.% nanofluids was prepared at five different sonication periods, beginning at 0 min, 30 min, 60 min, 90 min, and 120 min, to identify the best or ideal sonication time for hybrid nanofluids, and this step was considered necessary before shifting on to the next phase, as done by [19].

UV-Vis spectrophotometer

Figure 2 depicts the stability of 0.001% hybrid nano-cutting fluid after preparation for up to 30 days. Because of the varied sonication times, the light absorption values of all five nano-cutting fluids differ. It may be claimed that the sonication period affects the hybrid nanofluids' stability. This is because the light absorption strength is dramatically lowered during the four-week observation period. Because the nanofluid leaves a more particle-free region in base fluids, the absorption strength of hybrid nano-cutting fluid with 120 minutes of sonication duration is the lowest. The absorption strength of the hybrid nano-cutting fluid with 0 minutes, 30 minutes, and 60 minutes of sonication time was higher than the absorption strength of the hybrid nano-cutting fluid with 120 minutes of sonication time. The hybrid nano-cutting fluids with 90 minutes of sonication time had the maximum absorption strength compared to others with more than 90% absorption ratio when compared to an initial value which indicates that this sample has the best stability. Aside from that, during the sonication process, the nanoparticle was broken into smaller particles; the longer the sonication time, the smaller the particle would be. However, this study proved that 9 minutes of sonication was the optimum time for the process; if it exceeds 90 minutes, the particle tends to be too small and attraction between the particle increases, leading to agglomeration.

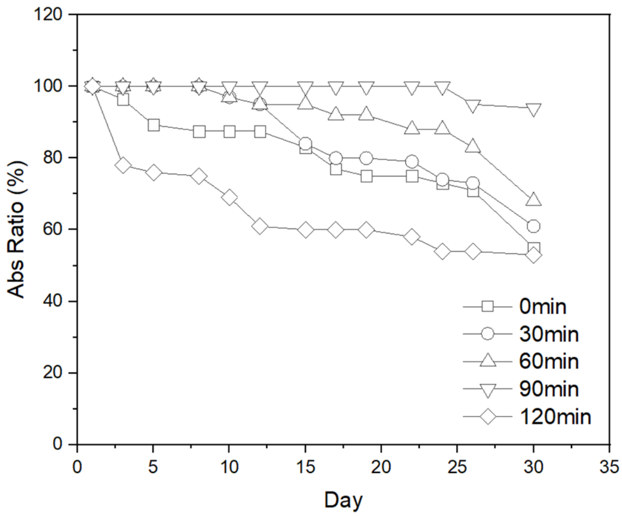

Fig. 2. UV-Vis. The spectrum obtained for Al_2O_3-TiO_2 hybrid nanofluid for 30 days

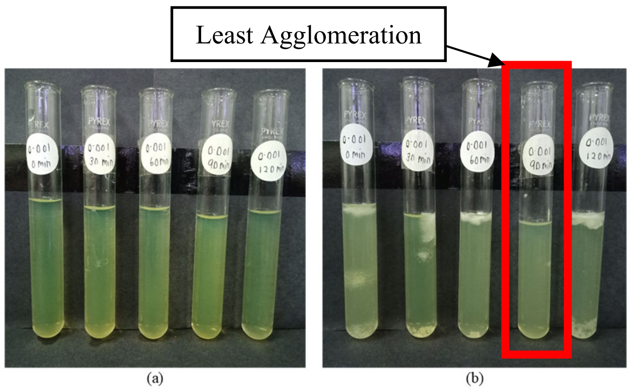

Fig. 3. Photograph of Al_2O_3-TiO_2 hybrid nanofluid at the static condition: (a) just after preparation, (b) after 30 days

Visual sedimentation

Photos of test tubes with nanofluid were obtained on the first day and after 30 days. Figure 3 (a) shows that the 0.001 vol per cent hybrid nanofluid does not display obvious nanoparticle sedimentation on the first day. It signifies that the nanofluids are stable just after they've been prepared. Figure 3 (b) demonstrates significant sedimentation at the bottom and top of the test tube in four out of five samples with 0.001 vol per cent hybrid nanofluid. When the nanofluids were kept static for four weeks, the stability of the nanofluids was poor at 0, 30, 60, and 90 minutes. However, when the nanofluids were kept static for four weeks, the nanofluids had good stability at 90 minutes.

3.2. Stability of different concentrations

Various dilutions of 0.00001 vol. per cent, 0.0001 vol. per cent, and 0.001 vol. per cent hybrid nanofluid were prepared at a sonication time of 90 minutes to verify the results of the optimum sonication time for this hybrid nanofluid, which is 90 minutes. This test was necessary so that researchers know the effect of different particle concentrations on nanofluid, as discussed by [20].

UV-Vis spectrophotometer

To get a valid result from the UV-Vis machine, required the samples were less viscose than the actual sample for the RSM experiment. Figure 4 shows the stability of 0.00001 vol. per cent, 0.0001 vol. per cent, and 0.001 vol. per cent hybrid nanofluids after just 30 days of preparation. The light absorption value of all three nanofluid concentrations differs from one another due to varying concentrations, as indicated. The stability of hybrid nanofluids is reported to be affected by varying concentrations. This is because the light absorption strength is lowered throughout the one-month observation period. The absorption strength of hybrid nanofluid with 0.00001 vol. per cent is the lowest, yet it still exceeds the absorption ratio of 80 per cent. The absorption strength of 0.0001 vol. percent hybrid nanofluid was slightly greater than 0.00001 vol. per cent hybrid nanofluid.

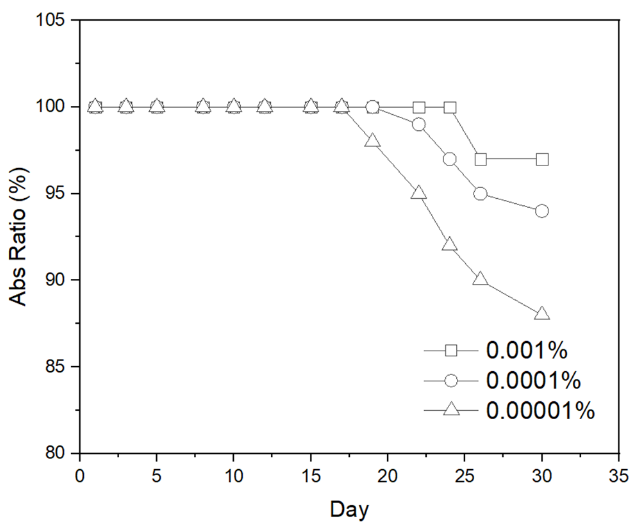

Fig. 4. UV-Vis. The spectrum obtained for Al_2O_3-TiO_2 hybrid nanofluid for 30 days

The hybrid nanofluids with 0.001 vol. per cent absorption strength, on the other hand, demonstrated the maximum absorption strength.

3.3. Stability of higher concentration

A higher volume concentration of nano-cutting fluid is required to be prepared so that the machining outcomes would be more significant [21]. For this higher concentration, visual sedimentation analysis was required to ensure that the nanofluid remained stable for a while. With a sonication time of 90 minutes, the nano-cutting fluids were prepared at volume concentrations of 1 vol. per cent, 2 vol. percent, 3 vol. per cent, and 4 vol. per cent.

Visual Sedimentation

Photos of test tubes with nanofluid were obtained on the first day and after 30 days. Figure 5 (a) shows that the 1 to 4 vol. per cent hybrid nanofluid does not display obvious nanoparticle sedimentation on the first day. It signifies that the nanofluids are stable just after they've been prepared. Figure 5 (b) demonstrates only little sedimentation at the bottom of the test tube and minimum colour separation at the top of the test tube in all four hybrid nanofluid samples. When the nanofluids are held static for four weeks, all of the samples show good stability.

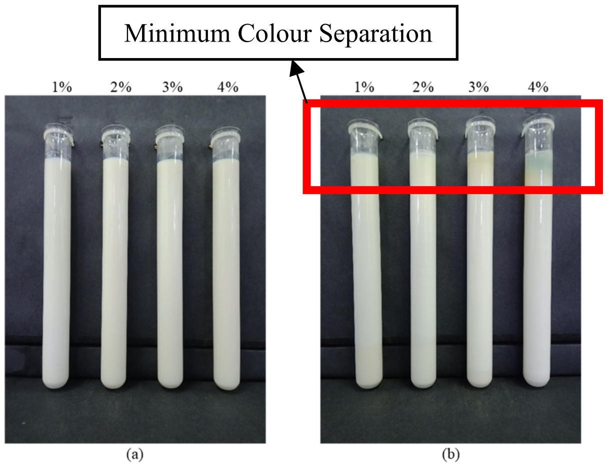

Fig. 5. Photograph of Al_2O_3-TiO_2 hybrid nanofluid at the static condition: (a) just after preparation, (b) after 30 days

3.4. Stability inspection by measuring Zeta potential value

Using Zeta Potential (Anton Paar, Lite Sizer 500), the Zeta potential value of the nanofluid generated for the experimental inquiry was determined. The observed value was around 30.0 mV. The synthesised nanofluid's observed Zeta potential value is not within the range of the Al_2O_3-TiO_2 hybrid nanofluid's iso-electric point. This measurement error assures that the nanoparticles in the base fluid are uniformly disseminated and stable. The measured Zeta potential value is not within the limit of iso-electric point nanoparticles due to very high repulsive forces among the nanoparticles [22]. Furthermore, after holding the nanofluid in a stationary condition for four weeks, very little settlement of nanoparticles was discovered, indicating that nanoparticles are stable in the base fluid.

For 0.00001 vol per cent volume concentration, Table 3 shows the zeta potential value. The zeta potential value for the Al_2O_3-TiO_2 hybrid nanofluid shows that the nanofluid concentration has a good zeta potential value. Table 4 shows the zeta value of 0.001 vol per cent volume concentration that indicates the nanofluid is in excellent stability. As a result, higher-concentration Al_2O_3-TiO_2 hybrid nanofluids are better suited for long-term use than lower nanofluid concentrations.

Table 3.
Zeta potential value of Al_2O_3-TiO_2 hybrid nanofluids

Particulars	After preparation (fourth week)
The volume concentration of hybrid nanofluid	0.00001 vol.%
Zeta potential values	37.6 mV

Table 4.
Zeta potential value of Al_2O_3-TiO_2 hybrid nanofluids

Particulars	After preparation (fourth week)
The volume concentration of hybrid nanofluid	0.001 vol.%
Zeta potential values	64.2 mV

4. Conclusions

This investigation was carried out to study the effect of Al_2O_3-TiO_2 hybrid nano-cutting fluid on stability. The nano cutting fluid Al_2O_3-TiO_2 at various volume concentrations. It is studied that the prepared nano-cutting fluids were characterised by UV-Vis spectrophotometer, visual sedimentation, Zeta potential analysis, and TEM photograph capturing techniques for analysing the stability of nano-cutting fluids. It is found that the best sonication time is 90 minutes, and the UV-Vis absorption value shows a stable value of over 80% while the visual sedimentation shows some sediment only, plus the Zeta value was in the range of good stability. TEM analysis also indicates the nanoparticles are well dispersed. Out of all four methods, it is suggested the best or most used method for the analysis of stability is UV-Vis spectrophotometer because it is a form of quantitative data that can be measured for a month. It is a cheaper method compared to other lab testing and easier for data presenting. Hence, the nano-cutting fluid is suitable for application in CNC machines using the correct equipment after proven its stability level.

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Additional information

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