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Experimental investigation on application of emulsifier oil based nano cutting fluids in metal cutting process

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Abstract

The purpose of cutting fluids in metal cutting process is to provide cooling and reduce the friction between tool and work piece at the shear zone. In dry cutting, the work piece is machined under dry conditions. The air surrounding the work piece acts as the cooling agent. Since air has low thermal conductivity it acts as a poor coolant. High temperatures at tool-work piece interface causes failure of cutting tools, formation of micro cracks and surface roughness of work piece is compromised. In wet cutting, the work piece is machined under wet conditions. Most cutting fluids constitute ninety five percent of water and five percent of cutting oil. Usage of cutting fluids have shown significant changes in thermal properties, tool wear, surface roughness and cutting forces on tool and work piece respectively.A study by few American institutes states that 60% companies are spending 20% more amount on their coolants/lubricants in a cutting operation than on cutting tool being used for machining. Uncontrolled microbial contamination of metal working fluids represents both economic and health risk. Minimum quantity lubrication (MQL) is alternative to this problem which uses minute amount of cutting fluids which is about three or four times less than that of the amount commonly used in a flood cooling condition.MQL requires a fluid with high heat carrying and lubricating properties. The present work investigates upon the usage of nano-graphite, nano -boric acid and nano-molybdenum disulphide in emulsifier oil based cutting fluids in MQL application. The primary work is to prepare a cutting fluid by including 0.3 wt% of nano particles and to check its stability, as dispersion of nano particles in base fluid is a challenging process. The prepared cutting fluids with nano inclusions are applied at a flow rate of 10ml per minute while performing turning operation under constant cutting conditions. Performance of cutting fluids are evaluated by measuring cutting forces, cutting temperature near chip –tool interface, tool wear and surface roughness for each turn . The results are compared with dry and MQL application with emulsifier oil without nanoinclusions.

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*Keywords:*Nanofluids; machining; boric acid; molybdenum di sulphide; graphite; cooling; Flank Wear; Forces; Machinability; Roughness; Wear.

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1. Introduction

In metal cutting, the basic purpose of cutting fluid is to provide cooling and lubrication. But, greater exposure to cutting fluids causes skin problems and even cancer in workers [1].Maintenance and disposal of cutting fluids are of main concern in terms of economy and safe disposal [2]. Minimum Quantity Lubrication (MQL) deals with these problems in an efficient manner. MQL refers to the usage of minimum amount of cutting fluids which is about three to four times less than that of the amount commonly used in a flood cooling condition. MQL system uses limited amount of coolant applied either as mist by mixing coolant with pressurized air or in the form of drops. Work has been done by many researchers on MQL techniques [3–6] and most of them reported it to be efficient than conventional flood cooling. The performance of MQL technique can be enhanced by the use of specialized cutting fluids having superior properties, for which nanofluids give a promising solution. Solids have good thermal conductivity compared to liquids. So, thermal conductivity of liquids can be enhanced by dispersing solids in it. Nano fluids are the fluids in which nanometer sized particles (Nano particles, Nano fibres, Nano wires, Nano rods & Nano sheets) are dispersed in the base fluids. Bizhan, sarhan and sayuti [7] studied the effect of inclusion of nano molybdenum di sulphide particles in CNC milling and found that the temperature and cutting forces are reduced. Vamsi Krishna et al. [8] used nanoboric acid in SAE-40 and coconut oil in turning with carbide tool and found significant reduction in temperature, surface roughness, and flank wear. M.M.S Prasad, R.R.srikant [9] studied the effect of inclusion of nano graphite inclusions to the cutting fluids and concluded that Increase in percentage inclusion of the nano graphite leads to better performance of the fluids in terms of properties and machining responses like cutting forces, temperatures, surface roughness and tool wear. Bin Shen [10] investigated the effect of MQL application of water-based nanofluids and oil-based nanofluids while grinding cast iron and found significant improvement in the overall grinding performance in MQL applications. Based on the literature review, the authors felt that, less work is reported on the application of Emulsifier oil based Nano cutting fluids in turning.

This paper deals with investigation of how the inclusion of nano particles influences the characteristics of cutting fluids. It includes preparation of various nanofluids and its stability evaluation using sedimentation method. The application of nano cutting fluids to machining is investigated and their effect on tool wear, cutting temperature, surface roughness and cutting forces respectively are analysed.

Nomenclature

MQL Minimum Quantity Lubrication
NG nano graphite
FNG functionalized nano graphite
NBA Nano boric acid
$nMoS_2$ nano molybdenum disulphide
SDBS sodium dodecylbenzenesulfonate
F_x force along x-direction, Thrust force
F_y force along y direction, Feed force
F_z force along z direction, Cutting force
R_a Arithmetic mean surface roughness
R_z Maximum height of the roughness profile
VB Flank wear
DOC depth of cut

2. Experimentation:

2.1 Preparation of Nano fluids:

Generally two step method is widely used in the industry. It is because this method is most economical to produce nanofluids in large scale. This method of preparation was used in this experimentation process. In this method

1. Nano particles are first procurred as dry powders by Nanoshel ,US.
2. Then the nano sized particles are dispersed into the base fluid with help of magnetic force agitation (or) ultrasonic agitations (or) high shear mixing.

In this work, ultrasonic agitation (bath sonicator) is used to mix the nanoparticles in the base fluid. Soluble oil was mixed with water in ratio 20:1 to form emulsifier oil as base fluid. Nanographite (80nm), nano boric acid (100nm) and nano molybdenum disulphide (100nm) were procured and 0.3 wt% of nanoparticles were dispersed in emulsifier oil using a bath sonicator.

2.2 Usage of surfactants

Generally, nano particles have high surface area due to this they have tendency to aggregate. The important technique used to enhance the stability of nanoparticles is the use of surfactants. These are often called as dispersants. It is easy and economic method to enhance stability of nanofluids. They contain hydrophobic tails and hydrophilic head. Surfactants are the compounds that lower the surface tension (or interfacial tension) between two liquids or between a liquid and a solid. It helps the Nano particles to disperse into the base fluid.Sodium dodecylbenzenesulfonate(SDBS) is the surfactant used in the present work.

2.3 Surface modification technique

Use of functionalized nanoparticles is a promising approach to achieve the long term stability of the nanofluids. In this process no surfactant is required to stabilize the nanoparticle suspension in base oil mixture, where the nanoparticles are surface coated. This surface coating can regulate stability and solubility of nanoparticles in the base fluid mixture. In our work, the procured nanographite is functionalized with acids so that oxygen functional groups are induced on the graphitic surface, which allow dispersion of nanographite in water.and used for experimentation.

2.4Nano fluid stability

As the emulsifier oil contains 95% water, the stability of nanopowders dispersed in water was initially checked using sedimentation method, to decide upon whether or not to use a surfactant.Functionalized nanographite (FNG), Nano molybdenum disulphide (nMoS_2) and nano boric acid (NBA) were dispersed in water without surfactant and with surfactant SDBS(Sodium Dodecyl Benzene Sulphonate).Dispersion of nanopowders in emulsifier oil was also checked with and without use of surfactant. Best method was used to prepare nanofluids to be used as cutting fluids.

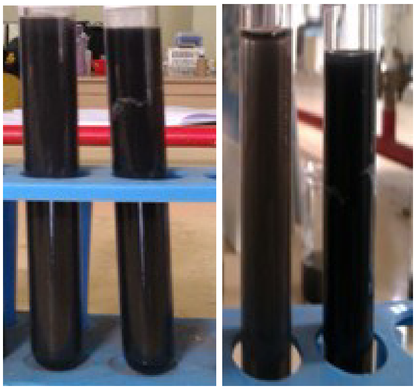
2.5Machining

Performance of different emulsifier based nano cutting fluids applied to machining is evaluated by performing turning at constant cutting conditions: cutting velocity, v = 65m/min, feed – 0.14mm/rev, doc – 0.75mm.Turning operation was performed on AISI1040 steel rod with uncoated cemented carbide tool bit (CNMG120408TTS). Cutting fluid was applied drop by drop at the cutting zone at a flow rate of 10ml/min.Their performance is compared with dry machining and MQL application with emulsifier oil without nanoinclusions.Cutting temperature near cutting zone was recorded using embedded tool thermocouple. Cutting forces were measured using Kistler Piezoelectric dynamometer. Cutting was interrupted at regular interval of time and tool was viewed in Olympus metallurgical microscope for measurement of maximum flank wear (VB).Surface roughness of the finished surface at different intervals was measured using Surftest SJ 301.

3. Results and Discussion:

3.1 Dispersion stability of nanopowders in water

0.3 wt% of FNG, NBA and $nMoS_2$ were dispersed in water with and without surfactant SDBS and checked for stability by Sedimentation method by allowing the samples to stand for certain amount of time. Fig 1 shows the samples of FNG in water without surfactant (Left side) and with surfactant (Right side) at the time of preparation (a) and after 1 day of preparation (b). Sample with surfactant showed better stability than that without surfactant.



(a) (b)

Fig 1: FNG dispersion in water without surfactant (Left side) and with surfactant (Right side) (a) at time of preparation (b) after 1 day of preparation.

Fig 2 shows the samples of nano boric acid in water without surfactant (Left side) and with surfactant (Right side) at the time of preparation (a) and after 1 day of preparation (b). Both samples with and without surfactant showed very good stability. This may be due to good solubility of NBA in water.

(a) (b)

Fig 2: NBA dispersion in water without surfactant (Left side) and with surfactant (Right side) (a) at time of preparation (b) after 1 day of preparation.

Fig 3 shows the samples of nano molybdenum disulphide in water without surfactant (Left side) and with surfactant (Right side) at the time of preparation (a) and after 1 day of preparation (b). Sample with surfactant showed better stability than that without surfactant.

(a) (b)

Fig 3: $nMoS_2$ dispersion in water without surfactant (Left side) and with surfactant (Right Side) (a) at time of preparation (b) after 1 day of preparation.

3.2 Dispersion stability of nanopowders in emulsifier oil

Based on dispersion stability of nanopowders in water, it was found that use of surfactant with FNG and $nMoS_2$ gave better dispersion while with NBA, good dispersion was obtained even without the use of surfactant. In order to check their dispersion stability in emulsifier oils, 0.3 wt% of FNG, NBA and $nMoS_2$ were dispersed in emulsifier oil (20:1). Surfactant was used with FNG and $nMoS_2$.No surfactant was used withNBA. Fig 4 shows the samples of (a) FNG (b) NBA and (c) $nMoS_2$ in emulsifier oil after 1 day of preparation. All samples were found to be stable.

(a) (b) (c)

Fig 4: Samples of (a) FNG (b) NBA and (c) $nMoS_2$ in emulsifier oil after 1 day of preparation.

3.3 Machining Performance

Emulsifier oil mixed in ratio 20:1 is used as the base cutting fluid.0.3wt % of FNG, NBA, $nMoS_2$ are mixed with emulsifier oil to form emulsifier based nano cutting fluids. Performances of different nano cutting fluids were evaluated by performing turning operation at constant cutting conditions. Performances were compared by measuring tool wear, cutting forces, cutting temperature and surface roughness. The results were also compared with dry machining and MQL application with emulsifier oil without nanoinclusions.

3.3.1 Tool wear:

Tool wear describes the gradual failure of cutting tools due to regular operation. Cutting was interrupted after regular interval of time and Maximum Flank wear was measured using the metallurgical microscope. Fig 5 shows the variation of tool flank wear (micrometers) with machining time while machining with conventional cutting fluid, nano cutting fluids and dry machining. It is found that MQL application of both conventional cutting fluids and nano cutting fluids showed reduced tool wear compared to dry machining. This was similar to that expected, as cutting fluid cools and lubricates the cutting zone and reduces tool wear compared to dry machining. Machining with nano emulsifier cutting fluids showed reduced tool wear compared to application of emulsifier oil. This may be due to improved properties of conventional cutting fluid with inclusion of nanoparticles. Among nano emulsifier cutting fluids, nano MoS_2 showed maximum reduction in tool wear which in turn increases the tool life. Fig 6 shows the tool wear photos for all cases at the end of machining.

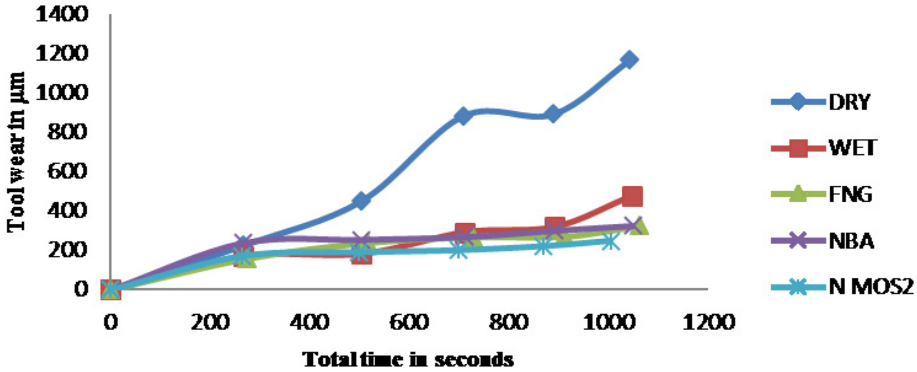


Fig 5: Variation of tool flank wear (micrometers) with machining time

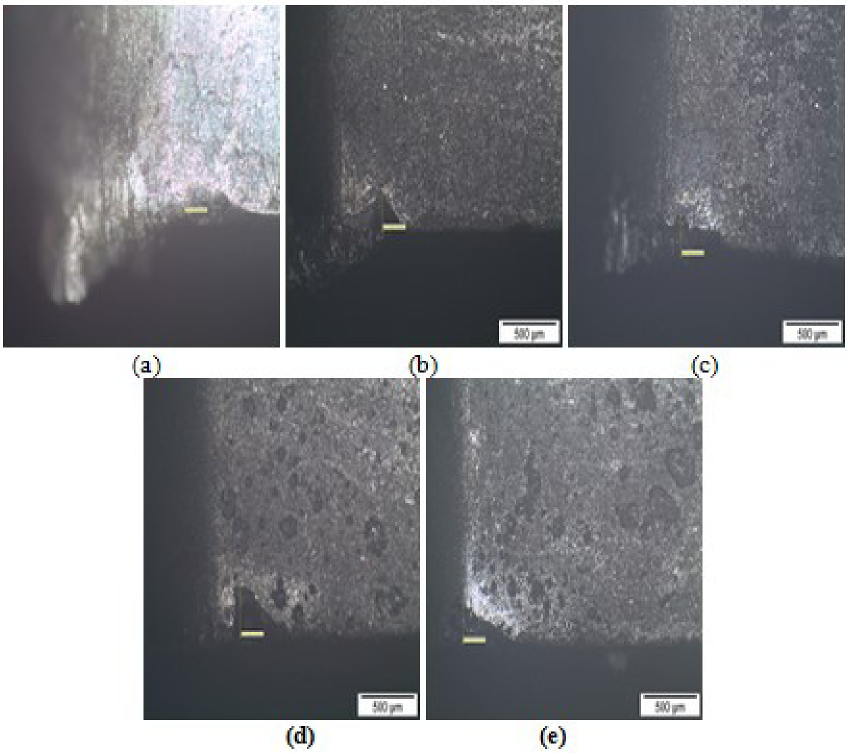


Fig 6: Tool wear photographs at the end of machining for (a)dry, (b) wet,(c) FNG, (d) $nMoS_2$ (e)NBA

3.3.2. Temperature:

The temperature was noted for time interval of 15 sec from thermocouple temperature display.Fig 7 shows the variation of cutting temperature with machining time. The fluctuations in the temperature graph are due to the removal and reinsertion of the tool for every cut (the tool removal and reinsertion is done to study the wear of the tool for each and every cut). Violet and red coloured lines shows that temperature in dry machining is very high and also in wet cutting up to some extent. Minimum quantity lubrication with inclusion of nano particles was found to be significantly better in reducing cutting temperature than dry and wet machining. The temperature that is generated at chip tool interface is found to be almost same with FNG and $nMoS_2$ emulsifier cutting oil. NBA showed lowest temperature initially and later temperature reduction was found to be similar to FNG and $nMoS_2$ emulsifier cutting oil.

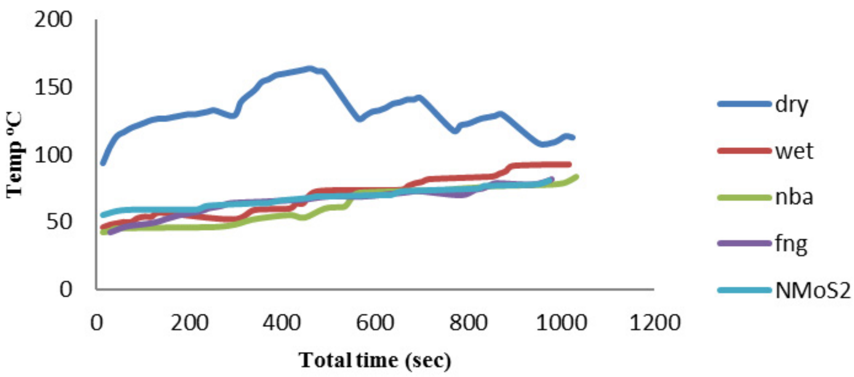


Fig 7: Variation of cutting temperature with machining time

3.3.3 Cutting forces:

The dynoware software in the computer was preset so that it records 4-Component (F_x, F_y, F_z, M_z). The forces were recorded from the time of contact of tool and work piece. Figures 8, 9 and 10 shows the variation of thrust force (F_x), feed force (F_y) and cutting force (F_z) with machining time.Net force F on cutting tool is given by

$$F = \sqrt{A^2}, \quad (1)$$

Where$A^2 = (F_x^2) + +(F_y^2) + (F_z^2)$

It was found that under the present conditions, $F_z > F_x >> F_y$. Hence it can be concluded that net force is more dependent on F_z. It was found that the overall forces had reduced when nanocutting fluids were used. Nano MoS_2 showed reduced cutting forces compared to other cutting fluids.

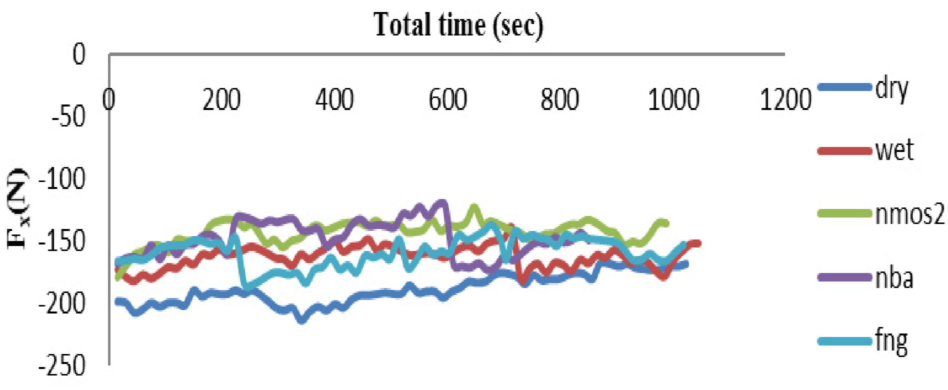


Fig 8: Variation of thrust force (F_x) with machining time

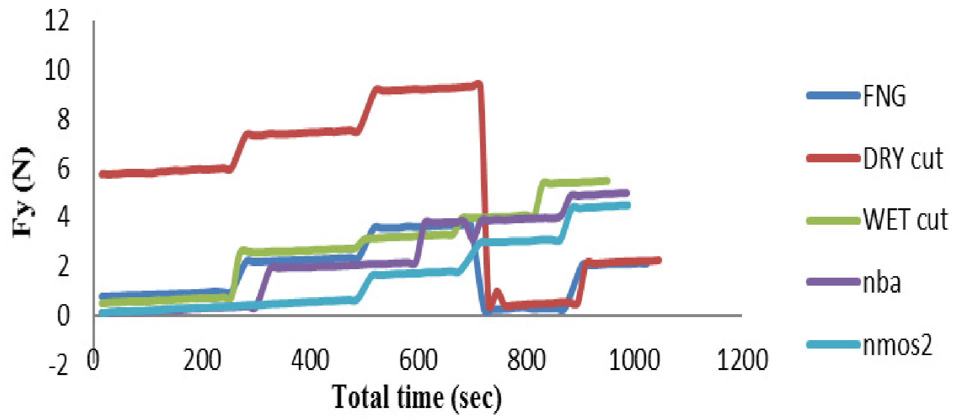


Fig 9: Variation of feed force (F_y) with machining time

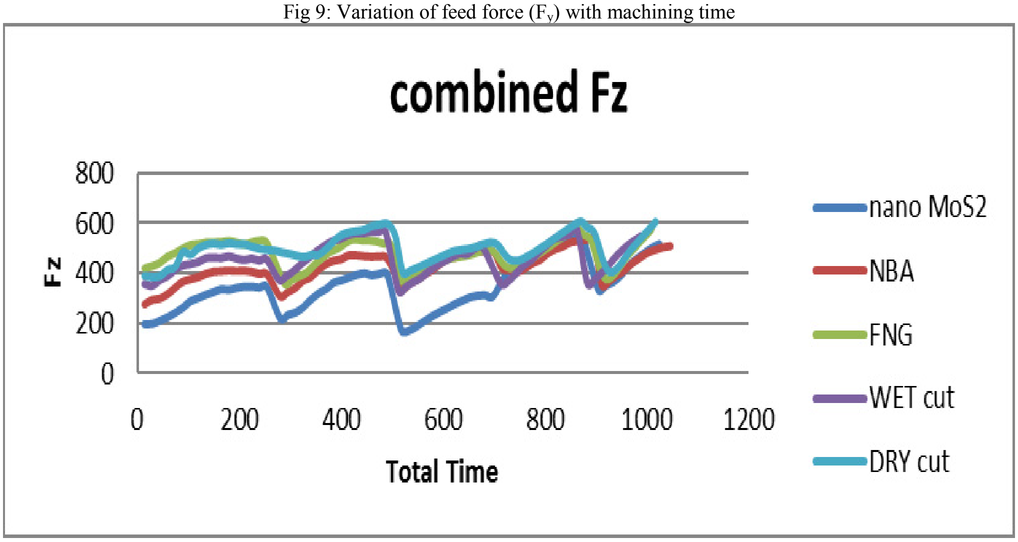


Fig 10: Variation of cutting force (F_z) with machining time

3.3.4 Surface Roughness:

Surface roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces .Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Roughness is measured with a profilometer in this work in terms of R_a(Arithmetic mean surface roughness) and R_z (Maximum height of the roughness profile). Figures 11 and 12 show the variation of surface roughness (R_a) and surface roughness (R_z) with machining time.

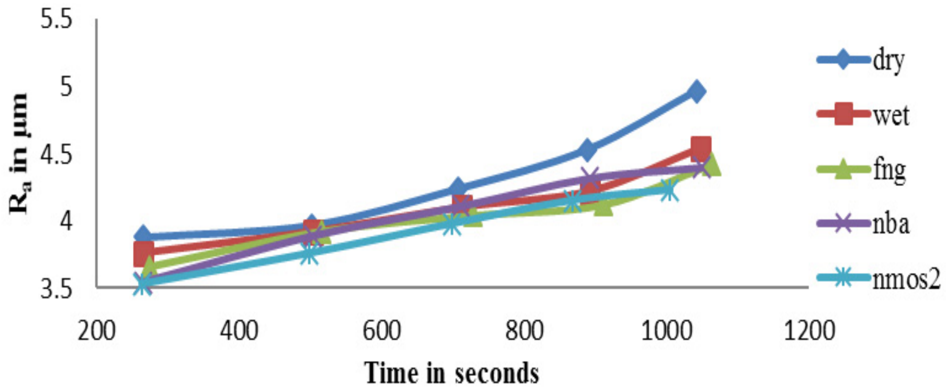


Fig 11: Variation of surface roughness (R_a) with machining time.

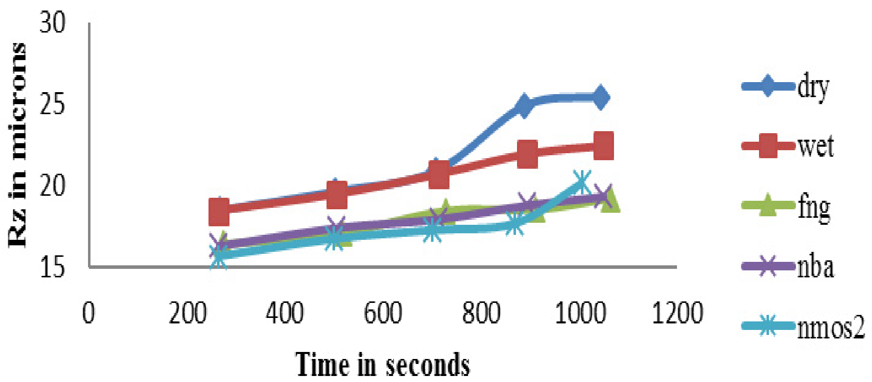


Fig 12: Variation of surface roughness (R_z) with machining time.

It is found that minimum quantity lubrication with inclusion of nano particles in emulsifier oil is significantly better than dry and wet machining. Nano MoS_2 is preferable as surface roughness of the work piece was less when compared to that obtained with other cutting fluids.

4. Conclusions:

- Functionalised nano graphite (FNG) showed good stability in emulsifier oil based cutting fluids than nano graphite (NG).
- FNG with SDBS showed much more stability than FNG.
- Addition of surfactant SDBS to nano MoS_2 gave good stability.
- Nano boric acid (NBA) is soluble in water so addition of the surfactant SDBS is not required.
- With respect to wear, nano MoS_2 showed better wear properties, next comes FNG, followed by NBA, followed by WET and finally DRY.
- With respect to surface roughness, nano MoS_2 showed better surface properties.
- With respect to cutting temperatures, NBA showed better heat dissipation properties.
- With respect to cutting forces, nano MoS_2 showed better properties.

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