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PERFORMANCE ANALYSIS OF CANOLA OIL BASED NANOFLUID AS LUBRICANT IN TURNING OF EN19 STEEL

S. Gautami* & N. Sateesh**

* PG Student, Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad

** Professor, Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad

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Abstract:

Machining is the most fundamental process in manufacturing industry. The heat generated at the tool work interface during machining is critical in deciding the dimensional accuracy and surface quality of work piece. Conventional cutting fluids are health hazardous for workers and cause environmental pollution. The present work focuses on the performance of vegetable oil based nanofluid on machining performance during turning of EN19 steel through minimum quantity lubrication (MQL). Canola oil is taken as base lubricant with varying nanoparticle inclusions of boric acid powder. Machining parameters like tool temperature and cutting forces are measured during machining. After machining surface roughness of the work is measured. Variation of cutting tool temperatures and the surface roughness of the machined surface with cutting speed and feed are studied at various percentages of nanoboric acid suspensions in canola oil. Cutting forces, tool temperatures and surface roughness have reduced with increase in percentage inclusion of nano boric acid particles.

Key Words: Canola Oil, Nanofluids, Boric Acid, Turning & EN19

1. Introduction:

Machining experiences high temperatures due to friction between the tool and work piece, thus influencing the work piece dimensional accuracy and surface quality. Machining temperatures can be controlled by reducing the friction between tool–work piece and tool–chip interface with the help of effective lubrication. Cutting fluids are the conventional choice to act as both lubricants and coolants. According to the US Energy Information Administration, the US consumed a total of 7.14 billion barrels of oil in 2008 (refined petroleum products and bio-fuels), which was about 23 percent of total world oil consumption 54 percent of these were automotive lubricants: engine oils and transmission fluids whereas 44 percent were industrial lubricants such as hydraulic fluids and gear oils [1]. Nearly all lubricants used in the automotive and manufacturing sectors are oil or grease based. These lubricants are usually toxic and not readily biodegradable; they can introduce significant quantities of pollutants into the waste stream. The long-term impacts that these lubricants have on the environment are cumulative and ultimately are dangerous to humans, plants, fish and wildlife. For this reason, the Environmental Protection Agency and other government agencies have imposed increasingly strict regulations on the use, containment and disposal of oil and grease based lubricants. These regulations have changed the landscape of the lubrication marketplace over the last decade as new lubricants are being developed to address a combination of environmental, health, economic and performance challenges. Since traditional lubricants often carry a health risk to humans during their primary use and disposal, and because disposal costs are nonlinearly increasing, it has become essential to develop and implement lubricants that come from non-toxic, natural resources. Further, the cutting fluids also incur a major portion of the total manufacturing cost. All these factors prompted investigations into the use of biodegradable coolants, dry machining, coated tools, cryogenic cooling, minimum quantity lubrication (MQL) and solid lubricants. Furthermore, the performance of vegetable oil base lubricant can be enhanced by adding micro/nano-particle with the lubricant. Solid lubricants are mostly used in aerospace industry although, for machining process mixed with a base fluid and in combination with MQL, can increase the lubrication performance. Sustainable lubricants are potential substitutes for mineral based cutting fluids. Vegetable base oils are readily biodegradable, environmentally friendly and may have the same or even superior tribological properties.

2. Literature Review:

Investigation on the use and performance of boric acid powder with palm kernel oil in comparison to conventional oil as a means of lubrication in machining AISI 431 steel with MQL is done by M.A.Mahadi. They found the average improvement in surface finish with boric acid powder aided vegetable oil lubrication was 7.21%. R. Padmini, P. Vamsi and G. Krishna investigated on the performance of vegetable oil based nanofluids on machining performance during turning of AISI1040 steel through minimum quantity lubrication (MQL). Different samples of nanofluids were formulated using dispersions of nano molybdenum disulphide (nMoS2) in coconut (CC), sesame (SS) and canola (CAN) oils at varying nanoparticle inclusions (npi) and examined for basic properties. It was observed that basic properties have increased with increase in npi, except absorbance. 0.5%CC+nMoS_2 were found to exhibit better machining performance compared to all the lubricant conditions. Cutting forces, temperatures, tool wear and surface roughness were approximately reduced by 37%, 21%, 44% and 39% respectively by using CC+nMoS_2 at 0.5% npi compared to dry machining. Experiments involving cemented carbide tool inserts and AISI 1040 stainless steel work material under varying machining parameters and with different lubricants were performed by P.VamsiKrishna et al. The lubricants prepared were nanoboric acid particle suspensions in SAE-40 oil and coconut oil. Thermal conductivity increased and specific heat decreased with percentage increase in nanoboric acid in base oil. Heat transfer coefficient increased slightly with increase in percentage of nanoboric acid in base oil and cutting speed. However, cutting temperatures, tool flank wear and surface roughness were decreased significantly with nanolubricants compared to base oil due to the lubricating action of boric acid. In all the cases, coconut oil based nanoparticle suspensions showed better performance compared to SAE-40 based lubricant, due to the

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better lubricating properties of the base oil. Further, in both the lubricants, performance was better in terms of cutting temperatures, tool wear and surface roughness at 0.5% nanoboric acid suspensions.

3. Experimentation:

A. EN19 Steel: EN19 is a high quality, high tensile steel; giving good ductility and shock resisting properties combined with resistance to wear. It is usually supplied in the form of round bars, steel flat bars, plates, hexagonal steel bars and steel square blocks. In the present work EN19 bars of length 120mm and diameter 20mm are used. The chemical composition of EN19 is tested and tabulated below in table 1.

Table 1: Chemical Composition of EN19

Element	Standard Range	Test Sample 1	Test Sample 2
Carbon	0.38-0.45%	0.529	0.524
Silicon	0.10-0.35%	0.33	0.34
Manganese	0.50-0.80%	0.626	0.628
Chromium	0.90-1.30%	0.997	1.00
Nickel	-	0.23	0.23
Phosphorous	0.035% max	0.31	0.32
Sulphur	0.035% max	0.021	0.021
Molybdenum	0.20-0.35%	0.18	0.18
Copper	-	0.07	0.08
Iron	Remaining	Remaining	Remaining

B. Preparation of Nanofluids: Boric acid particle size is initially tested on Horiba nano particle analyser and found to be 787nm. It is then ball milled on Retsch PM100 planetary ball mill for 3hours and 20minutes at an rpm of 400 with a ball to powder ratio of 10:1. An interval of 10minutes is taken every hour. Fig. 1 shows the a) weighed boric acid and washed 20 balls, b) boric acid and balls in jar and c) Retsch PM100 planetary ball mill. The so obtained boric acid is again tested on Horiba nano particle analyzer. The final size obtained was 334nm. At first premeasured quantity of boric acid particles of 334 nm size is taken in a beaker and required quantity of canola oil is slowly added while manually mixing both to obtain a uniform suspension. The nano suspensions thus obtained are placed in a bath type sonicator for an hour. After sonication it is observed that the particles are uniformly distributed without any agglomeration.

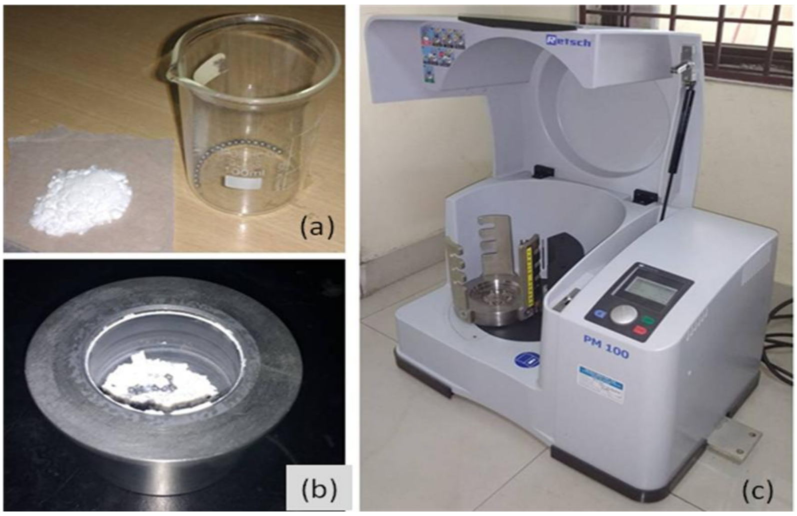

Figure 1: Weighed boric acid and washed 20 balls, b) Boric acid and balls in jar, c) Planetary ball mill

C. Machining: Experiments were conducted on Kirloskar Enterprise 1550 lathe machine at varying cutting conditions and at four percentages of nanoparticle inclusion to evaluate the performance of nanoboric acid powder suspension in canola oil during turning. Machining conditions are selected to suit the tool–work piece combination and MQL flow rate of 10ml/min [2]. EN19 steel work piece under different types of nanofluid lubricant environments was subjected to turning operation. Lubricant oil with solid lubricant suspensions was stored in tank and placed above the axis of machining. Lubricant storage container was open to atmosphere; hence flow of lubricant is due to its self weight and atmospheric pressure. Flow rate of lubricant mixture was controlled by a regulating valve. Initially lubricant mixture was collected in a vessel at different positions of the valve and flow rate is calibrated by measuring the volume of the lubricant collected in certain amount of time. In the trial tests we observed 10 ml/min flow rate is sufficient for selected cutting conditions and tool–work piece combination. Hence, it is taken and flow rate is kept constant. After ensuring the flow rate of 10 ml/min, experiments were conducted. Table II shows the process variables and their levels employed while conducting experiments. Depth of cut is kept constant at 0.3mm for all experiments. Table III shows all the machining conditions followed.

Table 2: Process Variables and their Levels

Symbol	Parameter	Levels			
		1	2	3	4
v	Speed (m/min)	40	53	63	79

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f	Feed (mm/rev)	0.14	0.16	0.18	0.2
%	Percentage of Nano Boric Acid	0	0.3	0.5	0.7

Table 3: Machining Conditions

Parameter	Value
Machine tool	Enterprise 1550 Lathe
Machining operation	Turning
Material of workpiece	EN19 steel (Ø20mm * 120mm)
Tool holder	PSLNR 2020M12
Cutting tool	CNMG120404 coated carbide
Depth of cut t (mm)	0.3 (constant)
Lubricant environment	Pure Canola, Canola + n H_3BO_3
Supply mode	Minimum quantity lubrication
Flow rate	10ml/min
Percentage of nanoparticle inclusion, n	0, 0.30, 0.50, 0.70
Ball mill	Make: Retsch PM100 Planetary ball mill Material feed size:<10mm No. of grinding stations: 1 Speed ratio: 1:-2 Drive: 3phase asynchronous motor with frequency converter
Lathe tool dynamometer	Capacity: 500Kg in X, Y and Z direction Tool size: 20mm square Sensor type: Strain gauge based 350Ω Bridge
Infrared camera	Make: Fluke Ti400 thermal imager Temperature range: -20°C to +1200°C Accuracy: ±2 °C Distance: upto 30m
Sonicator	Maximum power output: 600W Operating frequency: 20kHz Programmable timer: 1s-1h
Talysurf	Stylus material: Diamond Stylus radius: 0.005 mm Cut off length: 0.08-2.5mm Accuracy: ±3% of reading

The experimental set up is shown in Fig.2. Cutting forces are measured using lathe tool dynamometer which is fixed to the lathe tool post. A Fluke infrared thermal imager is used to measure the cutting tool temperatures at the tool tip. Thermal images are saved. Mitutoyo's Surftest SJ-210 is employed for measurement of average surface roughness (Ra). Tool tip temperature, cutting forces and surface roughness are measured for each turn, 3 readings for each lubricant condition are measured and the average is considered to avoid discrepancies in measurement.

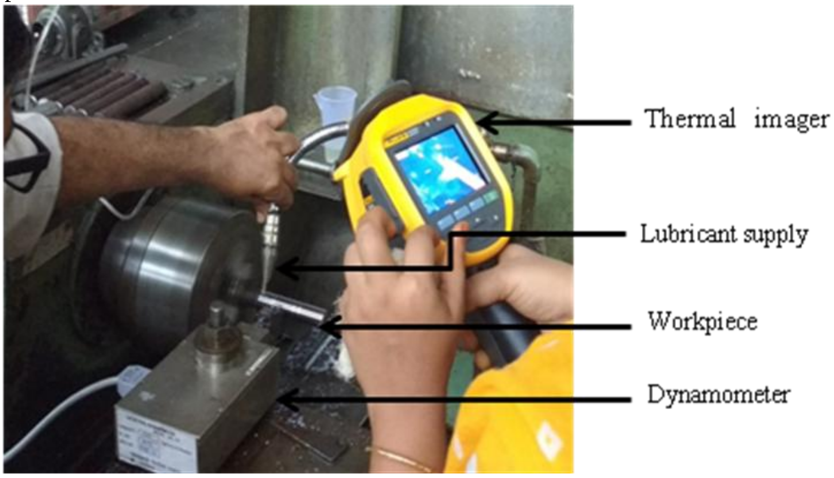

Figure 2: Experimental setup

4. Results and Discussion:

A. Cutting Forces: The variation of main cutting force (Fy) with speed and feed are plotted for all the compositions of nanofluids under test. Since Fy accounts for power consumption and specific energy consumption during machining, this component is considered in the present work.

Cutting speed Vs Main Cutting Force: Variation in main cutting force with change in cutting speed at npi (0%, 0.3%, 0.5%, 0.7%) at feed f=0.2mm/rev and depth of cut t=0.3mm is presented in Fig. 3. When comparing pure canola with 0.5% npi of boric

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acid in canola oil, observed a maximum of 25% reduction in cutting forces at feeds = 0.14 and 0.16mm/rev. The percentage reduction was 22% at feeds = 0.18 and 0.2 mm/rev.

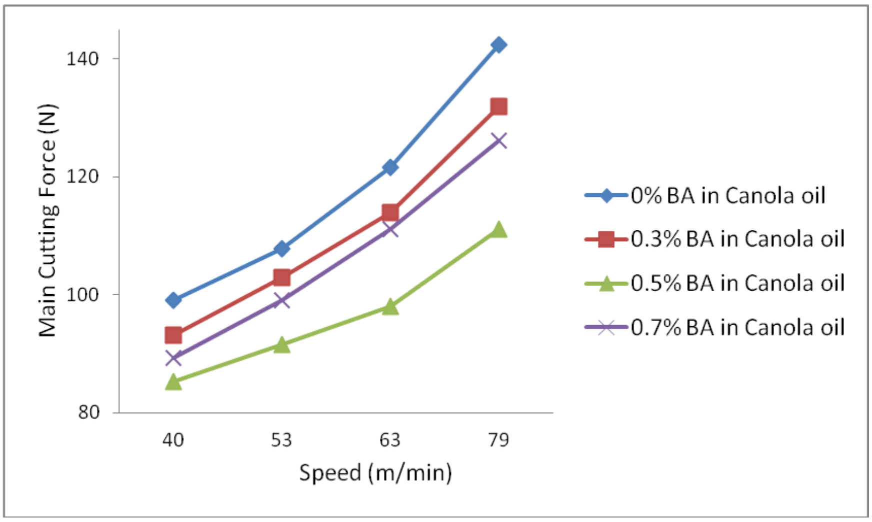

Figure 3: Variation of cutting force with speed at feed f=0.2mm/rev and depth of cut t=0.3mm

Feed Vs Main Cutting Force: Variation in main cutting force with change in feed at npi (0%, 0.3%, 0.5%, 0.7%) at speed v=79m/min and depth of cut t=0.3mm is presented in Fig.4. When comparing pure canola with 0.5% npi of boric acid in canola oil, observed a maximum of 25% reduction in tool temperatures at speed = 40 m/min. The percentage reduction was 16%, 20% and 22% at speeds = 53, 63 and 79 m/min respectively.

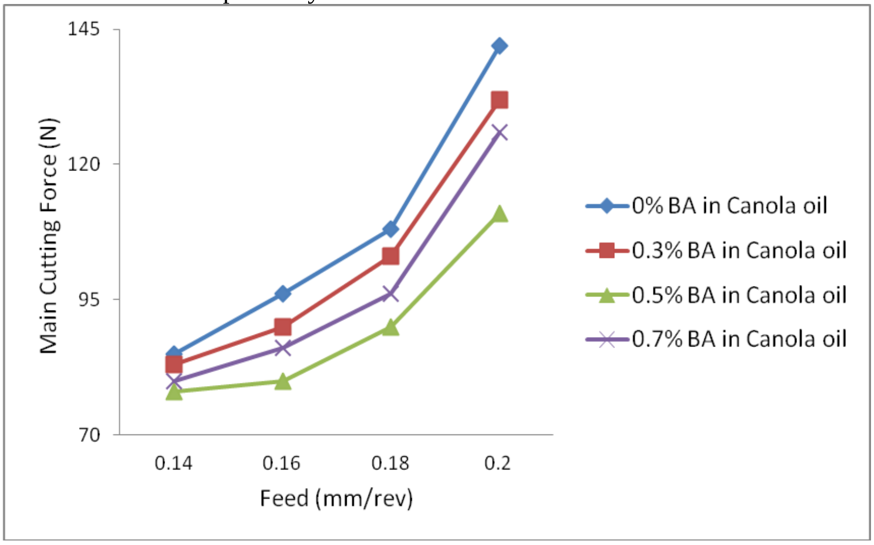

Figure 4: Variation of cutting force with feed at speed v=79m/min and depth of cut t=0.3mm

B. Cutting Temperatures: The cooling action of the lubricant with nanosolid lubricant suspensions was evident from the measurement of the cutting tool temperatures. The high lubricating property of canola oil is due to the fundamental composition of the vegetable oil molecules as well as the chemical structure of oil itself. Lubricity of vegetable oils arises from the oiliness property of its constituents, and its properties are the result of long, heavy and dipolar molecules. The polar heads of the molecules have great chemical affinity for metal surfaces and attach themselves to the metal like magnets [4]. The result is a dense, homogenous alignment of vegetable oil molecules, perpendicular along the metal surface that creates a thick, strong and durable film layer of lubricant. This combined effect of canola oil and nano solid lubricant particles is reason for reduction in the cutting tool temperatures. Even at high temperatures the lubricant separates the surfaces in contact [5, 6]. Among all, canola oil with 0.5% nanoboric acid particle suspensions performed well. This may be because, 0.25% boric acid cannot provide the adequate lubricating effect compared to 0.5%; 0.7% inclusions may reduce the flowability of the lubricant and prevent it from entering the cutting zone, thus decreasing its effectiveness.

Cutting speed Vs Cutting Temperature: Cutting temperatures increased with cutting speed irrespective of the lubricant. Variation in cutting temperature with change in cutting speed at npi (0%, 0.3%, 0.5%, 0.7%) at feed f=0.2m/rev and depth of cut t=0.3mm is presented in Fig.5. When comparing pure canola with 0.5% npi of boric acid in canola oil, observed a maximum of 18% reduction in tool temperatures at feed = 0.18mm/rev. The percentage reduction was 9%, 11% and 15% at feeds = 0.14, 0.16, 0.2 mm/rev respectively.

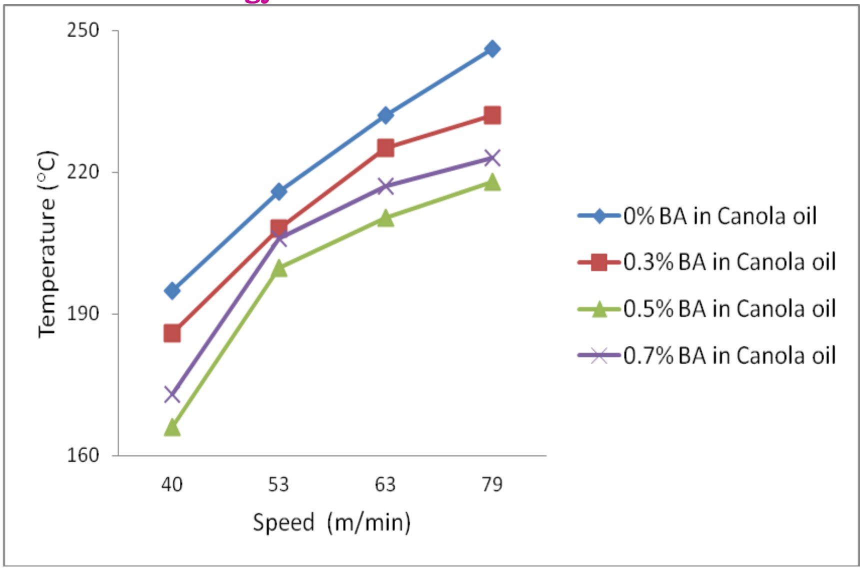

Figure 5: Variation of cutting temperature with speed at feed f=0.2mm and depth of cut t=0.3mm

Feed Vs Cutting Temperature: Cutting temperatures increased with increase in feed rate at all the lubricating conditions. Variation in cutting temperature with change in feed at npi (0%, 0.3%, 0.5%, 0.7%) at speed v=79m/min and depth of cut t=0.3mm is presented in Fig.6. When comparing pure canola with 0.5% npi of boric acid in canola oil, observed a maximum of 18% reduction in tool temperatures at speed = 79 m/min. The percentage reduction was 8%, 17% and 15% at speeds = 40, 53 and 63 m/min respectively.

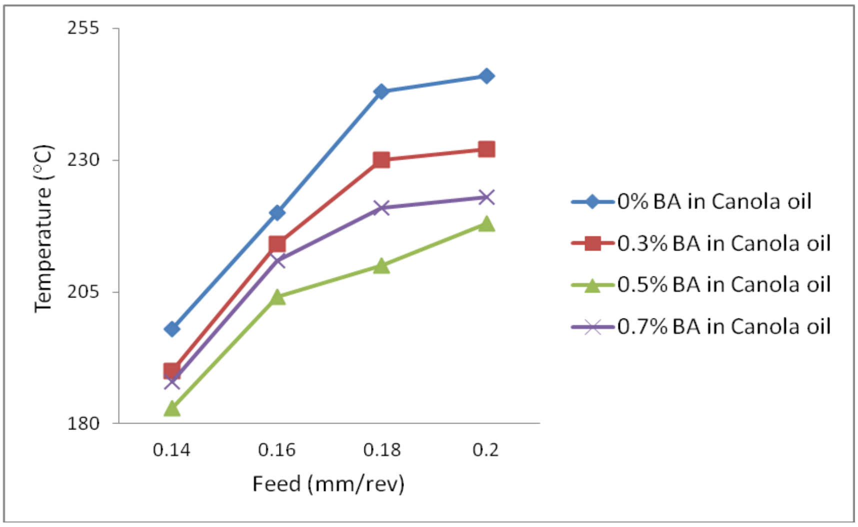

Figure 6: Variation of cutting temperature with feed at speed v=79m/min and depth of cut t=0.3mm

C. Surface Roughness: Among the selected lubricating conditions, surface roughness reduced with increase in percentage inclusion up to 0.5% and then started to increase. This is because of the lubricating action of the solid lubricant and canola oil. Two reasons might have influenced this phenomenon. One being, increase in specific density and viscosity of nanofluids with increase in npi. Due to which agglomeration of nanoparticles at higher npi takes place resulting in nonuniform dispersion in lubricant [7, 8]. The other reason is the influence of Vander Waals forces of attraction and repulsive forces, which persist amidst the particles when they advance each other. A suspension is said to be stable if the latter dominate the former [9]. This mechanism could possibly be the reason behind better absorbance of almost all the types of nanofluids considered in the present work up to 0.5%. Absorbance has not further increased or infact it has decreased because of the dominance of Vander Waals forces over repulsive forces resulting in aggregation of nanoparticles which settle down and the colloids (nanofluids) are not stable anymore. These factors can be imputed to the better absorbance of 0.5% npi when compared to other nanofluids.

Cutting speed Vs Surface Roughness: Variation in surface roughness with change in cutting speed at npi (0%, 0.3%, 0.5%, 0.7%) at feed f=0.2m/rev and depth of cut t=0.3mm is presented in Fig.7. Surface roughness reduced with increase in speed. When comparing pure canola with 0.5% npi of boric acid in canola oil, observed a maximum of 22% reduction in surface roughness at feed = 0.16mm/rev. The percentage reduction was 21%, 20% and 15% at feeds = 0.14, 0.18, 0.2 mm/rev respectively.

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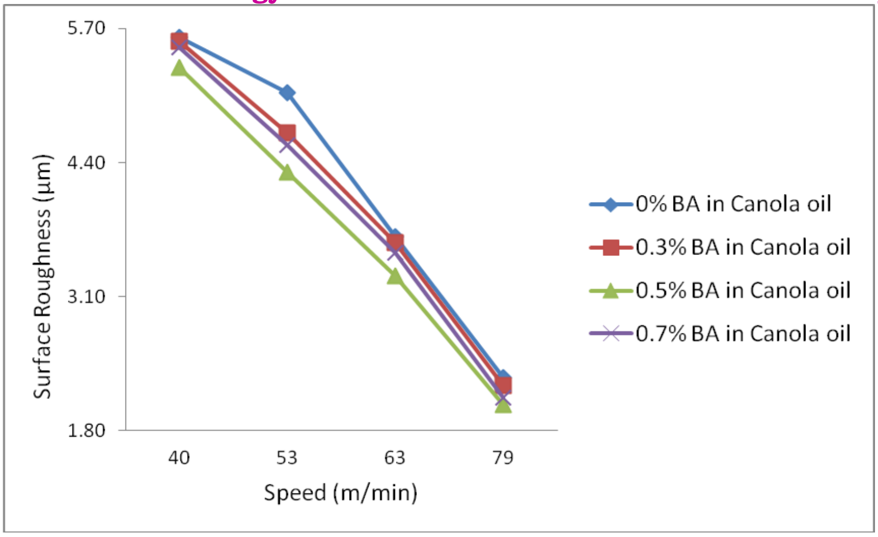

Figure 7: Variation of surface roughness with speed at feed f=0.2mm and depth of cut t=0.3mm

Feed Vs Surface Roughness: Variation in surface roughness with change in feed at npi (0%, 0.3%, 0.5%, 0.7%) at speed v=79m/min and depth of cut t=0.3mm is presented in Fig.8. It is observed that surface roughness increased with increase in feed rate. When comparing pure canola with 0.5% npi of boric acid in canola oil, observed a maximum of 22% reduction in surface roughness at speed = 79 m/min. The percentage reduction was 21%, 20% and 15% at speeds = 40, 53 and 63 m/min respectively.

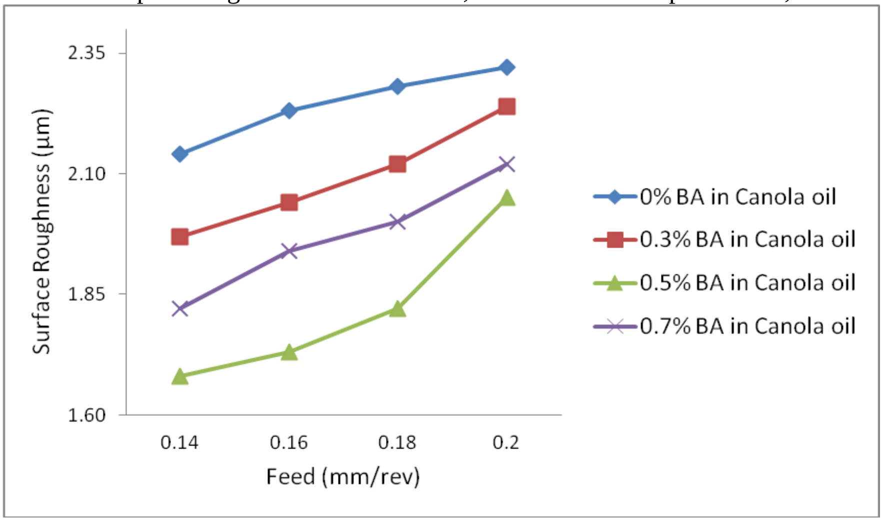

Figure 8: Variation of surface roughness with feed at speed v=79m/min and depth of cut t=0.3mm

5. Conclusion:

Experiments involving cemented carbide tool inserts and EN19 alloy steel work material under varying machining parameters and with different percentage inclusion of nano boric acid in canola oil as lubricant were performed.

- ✓ Amongst all the cases (0%, 0.3%, 0.5% and 0.7%) 0.5% of nanoparticle inclusion of boric acid in canola oil showed better performance.
- ✓ Cutting forces approximately reduced by 22% by using 0.5% npi when compared to pure canola oil as lubricant in machining.
- ✓ Cutting temperatures reduced by 14% with 0.5% npi when compared to pure canola oil as lubricant.
- ✓ Surface roughness reduced by 20% by using 0.5% npi when compared to pure canola oil as lubricant.
- ✓ The reduction in cutting forces, cutting temperatures and surface roughness may be attributed to lubricant's better lubricating action, which reduced the frictional forces between the tool and work piece there by reducing the temperatures developed and ultimately preventing tool wear, thus prolonging tool life, resulting in surface quality improvement.

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S. Gautami graduated in Mechanical Engineering from Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, 2010. She worked as Design Engineer for 2 years on design and analysis in Cyient Limited. She is pursuing master of technology in Design for manufacturing from Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad.

N. Sateesh graduated in Mechanical Engineering from Nagarjuna University AP, India, 1992. He has done his master degree from JNTUH Hyderabad, India, 2002 in CAD/CAM specialization. He has awarded doctorate degree in Mechanical Engineering from Osmania University, Hyderabad, India, 2010. He has 6 years of industrial experience and 17 years of experience

in teaching and research. His area of research is in CAD/CAM, Composite materials, modeling, and simulation. He has published more than 33 papers in international journals and conferences. He is member of ASME and fellow of Institute of Engineers, India. Presently he is working as Professor in Mechanical department of Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India.

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