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Effect of Hybrid Plant-based Cutting Fluid in Turning Operation of EN19 Steel and Modelling of Heat Transfer Equation for Multiple Phase Colloids

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Abstract

This article describes a project where an alternative to conventional Mineral Oil (MO) based cutting fluids is tried on the turning operation of steel samples. The deposit of petroleum is getting depleted day by day, the pollution due to fossil fuel is increasing exponentially and petroleum is getting more and more expensive. Due to these reasons, nonpetroleum (MO) based alternative cutting fluids have been in business for quite a while. There is still active research going on to find a good alternative to replace MO-based cutting fluids. The article demonstrates the experimental result of non-mineral oil based cutting fluid composed of Brassica nigra (mustard) seed oil and helianthus annuus(sunflower) seed oil mixed with water, suspended Graphite particles and lecithin is applied on EN 19 steel subject to turning operation by high-speed steel turning tool. The effect of the cutting fluid on friction, average cutting temperature, average cutting tool life, and roughness of the finished surface, are studied in this project. A heat transfer model has been described which may be a good fit in this case. A significant development in the machined surface quality has been encountered alongside a fall in average cutting temperature.

Keywords: Hybrid Cutting fluids; Heat transfer; turning; surface finish; Cutting temperature

INTRODUCTION

Machining is a very important operation in any quality manufacturing process. It is a material removal method where by removing materials from stock, we get the desired dimensions and shapes. The machining is successfully done by carefully designed and selected cutting tools and cutting parameters. There are different machining processes meant for different operations like bulk material removal, surface finishing etc. During cutting operations like turning chips form and the chips get separated from the workpiece due to shearing along the shear plane. At the principal shear zone shown in Figure 1, region A (where chips break along the shear plane) as a major fraction of mechanical energy, transferred with the cutting force, gets converted to heat, a huge temperature rise is observed there. There is a nose part of the tool, and a part of the energy transferred by the cutting force is reportedly converted to heat, which is shown in the region B of Figure 1.When the chips flow over the cutting tool (Secondary deformation zone), both surfaces rub against each other which is shown in Figure 1, region C. This causes friction and therefore huge heat generation leading to rapid wear of the cutting tool, scars on

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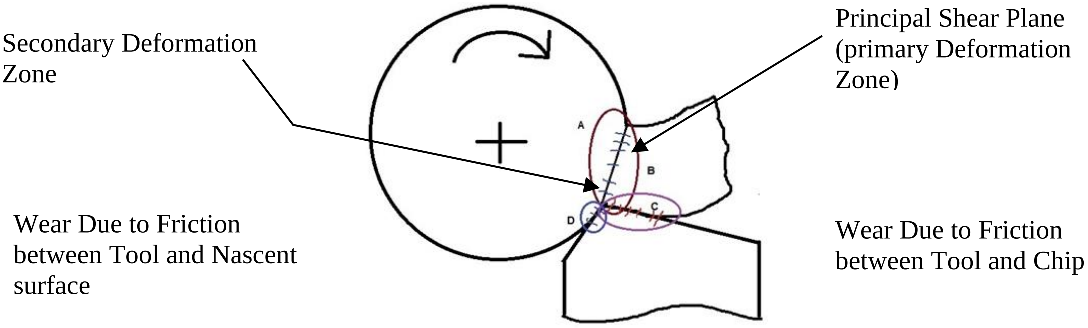

Figure 1. Sources of heat generation in metal cutting.

the job, built up edge formation etc., and finally results in poor product quality and loss of material. Heat is also generated due to the friction between the worn-out tool surface and the finished workpiece surface as shown in the Figure 1, region D. In order to reduce friction and possibilities of thermal degradation, cutting fluids are essential during cutting operations like facing, turning, milling, grinding etc. Cutting fluids not only help in reducing the friction but also while machining they carry away the heat generated at the chip tool interface and sometimes they help in protecting the nascent surface from external corrosion. Now it is obvious from the above discussion that chips actually take away the major portion of the generated/converted heat as they break from the main workpiece, but the remaining heat causes poor finishing of the workpiece. Though a higher temperature of cutting reduces the cutting force that could not be a reason for compromising with tool life or quality of the machined workpiece. Due to this reason several methods have been employed so far to reduce heat generation and friction. However, when it comes to the dissipation of the generated heat during cutting or reduction of the coefficient of friction, the application of cutting fluid has always been a great option. At the chip-tool interface especially during high-speed cutting fluid cannot enter due to interlocking caused by plastic deformation. Several materials could be used as a cutting fluid starting from water to even enzymes secreted from different bacteria. Water is always good for carrying away the heat but it has no significant effect on the coefficient of friction. The boiling temperature of the cutting fluid should be high because if during turning the cutting fluid starts to boil at an early stage then it would not serve the purpose of lubrication or cooling properly. The film conductivity should also be good otherwise proper cooling would not be achieved. Numerous researches have been made till to date in the quest for a good cutting fluid which would exhibit the mentioned characters.

In the beginning, all such cutting fluids were obtained from petroleum-based mineral oils (MO). Several additives have been tried with those oils to enhance their qualities in terms of the mentioned parameters. Some offered better thermal conductivity; some reduced the coefficient of friction, and some offered both. In the present condition, it has been found that the MO stock of earth is gradually decreasing and the price of fossil fuels is gradually rising. In this condition depending only on the MO-based cutting fluids does not seem to be a good idea. Numerous researches have been made to find the alternatives. Ogedengbe et al. [1], showed the various deformation and wear zones during turning operation using a single-point turning tool. D'Addona et al [2]., tested microorganism-based sustainable cutting fluids using a sintered carbide tool to lay a basis for Biological Transformation in Manufacturing (BTM). However, using biological agents for lubrication is hazardous to one's health. Ávila et al. [3], compared turning performance during machining of AISI 4340 hard-to-cut steel under different MQL fluids such as vegetable cutting oil, synthetic oil, and petroleum-based oil. They found that the life of the cutting tool as well as lower surface roughness achieved with the application of vegetable-based oil. Khan et al. [4] and Costa et al. [5], one of the experiments showed the effect of biodegradable vegetable oils applied in the MQL technique on different metal cutting. They showed there is a significant improvement in tool life and reduction in burr height while using vegetable oil in MQL than using mineral-based oil in MQL. Designing an MQL apparatus requires expertise and skill. Singh et al. [6], have been tested with tobacco oil with CuO nanoparticles, that CuO improves the thermal properties of cutting fluids. Zedan et al. [7], made trials with Mustard seed oil and found that at low load it shows the least wear scar diameter and flash temperature parameter. Rodrigues et al. [8], Experimented with Sunflower seed oil on ABNT 1045 Carbon steel and found that it has a significant influence on the feed force and cutting velocity. Singh [9] stated that vegetable oils are made up of triglycerides along with long fatty acid chains. The long chains of fatty acids stable lubrication film to prevent tool wear. Bibin et al., [10] analysed non-edible feedstock as a renewable fluid used in sustainable machining. They tried with mesquite oil which was subjected to transesterification. They have emphasized that the use of bio-oils would reduce the numerous health hazards which are encountered in mineral oil-based cutting fluids. Ladakhi et al., [11] have reviewed extensively the effect of vegetable oils in metal-cutting operations. They have also mentioned the biohazard of MO cutting fluids. Alaba et al., [12] have experimented with palm kernel seed oil in turning of AISI 1039 Steel. They used Taguchi L_9 orthogonal array to design their experiment. They experimented with three variables namely speed, feed and depth of cut. In this experiment, however, the variables are the same. Liu et al., [13] have mentioned that vegetable oils offer a better viscous effect which would help in the reduction of the temperature of the nascent surface. Sani et al., [14] have experimented with Tamanu plant-based oil in metalworking as a biodegradable fluid. They have found significant improvement in the tribological properties of the nascent surface.

It has been observed that vegetable oils are good substitutions for MO-based oils, typically in medium-load operations. In this project, an attempt has been made to find the cutting fluid based on plant seeds to achieve the best cutting conditions on EN19 steel subjected to turning operations. Brassica nigra (mustard) seed oil and Helianthus annuus (sunflower) seed oil has been mixed in different proportions with variable amounts of graphite micro powder additive to obtain two different samples of cutting fluids. We have tested their friction reduction capacity, temperature reduction capability and corrosion prevention quality on the turning operation of EN19 steel using an HSS cutting tool at different cutting speeds, feed and depths of cut.

EXPERIMENTAL DETAILS

A few trials have been made on EN19 samples on a conventional lathe with HSS single-point tool. Two samples of cutting fluids were taken; however, the primary constituents were the same by chemical nature. The properties of Brassica nigra (mustard) seed oil, Helianthus annuus (sunflower) seed oil and mineral oil are represented in the Table 1.

Table 1 suggests that the specific heat of sunflower oil is highest among all three oils under interest, so sunflower oil produces the best cooling effect as we all know, heat transfer per unit mass flow rate-

$$Q = c_p \Delta T \qquad (1)\ [15]$$

The higher the c_p, the lower will be the ΔT value. The thermal conductivity of mustard oil is highest among the three (Table 1). Definitely, mustard oil will carry more amount of heat easily. Now at a high load condition, mustard oil has a low friction reduction property due to its high viscosity value (Table 1). In order to overcome this issue a certain amount of sunflower oil mixing is done and the result we found is quite satisfactory. Although sunflower oil is staple oil across the globe but it is a good alternative if we consider the low flash point and fire point of the mineral oil. Moreover mineral oil vapour is one of the chief pollutants and also due to gradual depletion of mineral oil stock the price is rising. As EN19 is a medium carbon, improved mechanical property steel, dry cutting would always result in astronomical friction. The chemical composition and mechanical properties of EN19 steel are shown in Table 2 and Table 3 respectively.

It is evident from Table 2 that the carbon content of this steel is in the medium carbon steel range, so this steel is relatively harder than MS samples or any typical ductile material. Although EN19 is structural steel hence it is ductile but, with improved hardness. Table 3 indicates the tensile strength of this steel is much larger and elongation at break is also higher which indicates it’s retention of ductility, however, if not subjected to suitable cutting conditions; it would show a brittle fracture in shear during turning. A lathe with 6 spindle speed 4 jaw chuck and all geared headstock was used.

Table 1. Properties of different oils

Properties	Mustard oil	Sunflower oil	Mineral oil
Kinematic Viscosity, $\vartheta = \frac{\mu}{\rho}$(ctst) at 100˚c	9.79	7.78	1.00
Density,ρ (kg/m^3)	885.6	930	900
Specific Heat, c_p(kJ/kg K)	1.98	3.19	1.67
Flash Point(˚c)	310	315	220
Fire Point(˚c)	350	371	262
pH Value	6.5	7.38	8.9
Heat Transfer Coefficient, k (W/mK)	0.169-0.174	0.168	0.106

Table 2. Chemical composition of EN19

Element	Percentage present
Carbon (C)	0.37-0.46
Chromium (Cr)	0.91-1.48
Manganese	0.48-0.82
Molybdenum (Mo)	0.22-0.38
Silicon (Si)	0.16-0.29
Phosphorus (P)	0.036 (approximately)
Sulphur (S)	0.042(approximately)

Table 3. Mechanical properties of EN 19

Properties	Metric
Tensile Strength	655.2 MPA
Yield Strength	414.79 MPA
Bulk Modulus (Typical for Steel)	141 GPA
Shear Modulus (Typical for Steel)	80.02 GPA
Elastic Modulus	190-209.85 GPA
Poisson's Ratio	0.26-0.31
Elongation at Break (In 50 Mm)	25.68%
Hardness, Brinell	197.04
Hardness, Rockwell C	12.96
Hardness, Vickers	207.10
Machinability	64.92

Experimental Conditions

The experiment was carried out, keeping a few parameters constant as mentioned in the Table 4. These parameters were chosen carefully in order to make an assessment of the operation against variable cutting parameters. The constant parameters are like the chemical constituents of the cutting fluid, flow rate of the cutting fluid, the tool which have been used (fixed tool nomenclature) and obviously the temperature of the surroundings which have a significant effect on assessing the heat transfer process during turning.

The parameters which were varied during experiment to prepare the dataset are also shown in Table 4. These parameters are speed of spindle, feed rate and depth of cut. Speed of spindle directly related to the heat generation as the cutting power directly gets converted to thermal energy at the shear plane. Excess heat generation affects the tool life. The feed rate has pronounced effect on the surface roughness of the nascent surface. Depth of cut is also related to the heat generation and tool life. Hence the mentioned three parameters are very crucial during turning and that is why they have kept variable during the whole operation.

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Table 4. Fixed and variable process parameters and range:

Fixed Conditions	
Process parameter	***Fixed Conditions***
Chemical composition of the cutting fluid.	Brassica nigra, Helianthus annuus, Water, Graphite particle, Lecithin
Flow rate of the cutting fluid.	33.28 m^3/s
Tool nomenclature	12,15,7,6,10.15,0.8
Surrounding temperature.	32°c
Variable Conditions:	
Parameters	***Range***
.Speed of spindle.	500 rpm-1000 rpm
.Feed rate.	2 mm/rev-4 mm/rev
.Depth of cut.	2 mm-3 mm

Table 5. Chemical composition of cutting fluid.

Constituent	Sample 1	Sample 2	Sample 3
Brassica nigra	50 ml	50 ml	50 ml
Helianthus Annuus	50 ml	50 ml	50 ml
Water	200 ml	200 ml	200 ml
Graphite micro particles	-	2 g	2 g
Lecithin	-	-	1.5 ml

Experimental Procedure

The experiment was carried out in a 4 jaw chuck lathe with bed length 1500 mm and 6 spindle speeds. The turning operation was done on EN 19 steel with a high speed steel turning tool. At first the turning was done without the cutting fluid, which is called the dry cut condition. The temperature of the nascent surface was measured by a thermal gun (Laser type) and the surface roughness was measured by a talysurf (Mitutoyo SI-210 series). The noise and vibrations however were never measured, they are mentioned here based on perceptions. The turning was done with two spindle speeds of 500 and 1000 rpm and two feed rates 2 mm/rev and 4 mm/rev. Two depth of cuts were selected, 2 mm and 3 mm. These same parameters were applied and another set of measurements were taken when a cutting fluid constitutes of Brassica nigra, Helianthus annuus and water was used. The same experiment was repeated with another two samples of cutting fluid comprising the above mentioned constituents with graphite powder (micro particles) and graphite with lecithin respectively. The temperatures, surface roughnesses were measured using the same tools. The different compositions of the three samples of the cutting fluid are shown in the Table 5.

RESULT AND DISCUSSION

Dry cut condition offers the most severe cutting conditions due to huge heat generation at the principal shear zone and secondary shear zone as already mentioned. Due to this reason, as mentioned in Table 6, the chips were found to be red at 500 rpm spindle aped and when spindle speed was increased to 1000 rpm it turned blue because the frequency of blue radiation is higher and it is obtained at higher temperature. However as the cutting force was initially very high, it caused a huge vibration of the work piece and the roughness was very poor due to this reason. The scallop marks were very prominent which have been mentioned in the last column of Table 6. Sl no. 5-8 of Table 6 shows that there is an improvement of surface roughness after application of sample 1 of cutting fluid the composition of which is mentioned in Table 6. The temperatures of turning are also get reduced simply due to lower of coefficient of friction. A significant improvement in surface roughness and temperature distribution (lowering of temperature) has been observed in Sl no. 9-12 of Table 6.

During dry cut discontinuous chips were found as the cutting condition tends towards brittle failure of the workpiece. the cutting fluid application mostly resulted in continuous chip formation with plastic deformation (Table 6). At elevated temperatures, although machining became easier due to a reduction in the hardness of the workpiece it took the cutting condition very near to the built up edge condition with red coloured chips and burnt marks on the workpiece. When the depth of cut was increased due to more intense mechanical energy application, more heat was generated and the friction also played a very significant role there. The chips turned blue due to higher temperature (blue colour has more frequency than red colour and obtained at higher temperatures). If we closely look at Table 6, it is clear that by adding graphite particles (micro) the thermal property has been improved however at higher DOC the friction is still an issue which is causing noise and vibration of the tool tip. The underlying cause may be due to the cantilever arrangement of the cutting tool and at higher depths of cut the load on the tool tip becomes severe causing huge deflection of a periodic nature. However, since the cutting fluid here is an emulsion which means the entire system (as considered in terms of thermodynamics) is not homogeneous and isotropic. It has different densities in different parts with multiple phases, one dispersion medium (water) and three dispersed phases namely Brassica nigra (mustered) seed oil, Helianthus annuus (sunflower) seed oil and graphite microparticles (in one of the samples). One thing is clear the inclusion of graphite microparticles definitely improves tribological and thermal properties. Graphite here has a significant effect on tribological properties as well thereby improving the coefficient of friction.

After adding lecithin, it was observed that the appearance of the mixture became cloudy, which is typical for a good emulsion. Lecithin contains one lipophilic group and one hydrophilic group [16, 17], which hold both the water and oil part together and creates a good emulsion which is more stable than both sample 1 and 2. If we look closely at Table 6, the chip formation is continuous type even when the cutting speed was raised alongside an elevated DOC. The maximum temperature of cutting is only 94.5˚c which is much less than the previous cases. At lower cutting speed and DOC, the boiling of the fluid was not there as the lecithin held water and oils very tightly [16, 17]. However, at the elevated cutting speed and DOC when the temperature raised the bonding of lecithin with water and oil got weaker as water had the lowest boiling point among all the fluids, a part of the water started boiling and visible vapours were there. The fluid was applied in a particular quantity so that the condition of pool boiling could prevail.

We know that during material removal through turning, shaping or even milling, cutting fluid cannot enter into the tool-work piece interface. So the principal focus is generally to prevent a temperature rise of the workpiece, and thereby the chance of thermal wear and degradation of the workpiece material and to preserve the grain structure of the material.

The method of application of the cutting fluid can be described in Figure 2. We have applied the cutting fluid tangential to the workpiece surface. Now when the workpiece is steady and if we apply the fluid tangentially, a stream from the fluid would diverge towards the workpiece as the pressure of air between the workpiece and the cutting fluid gets reduced due to the increase in kinetic head and the air on the other side of the cutting fluid pushes the fluid towards the workpiece (Figure 2). This is called the Coanda effect. Now when the workpiece starts to rotate the fluid naturally due to no slip condition gets smeared all over the workpiece and forms a very thin layer of fluid which provides the required heat transfer (taking heat from the piece) and also the thin film lubrication to reduce friction. This thin layer is called the boundary layer. Now the cooling method involves boiling as stated earlier but here the fluid is a multiphase fluid where the water is the suspension medium and both the oils and graphite particles are suspended parts. The fluid offers a forced convection boiling effect, where the initial cooling (prior boiling) is governed by forced convection principles and during boiling, as the whole workpiece is covered by the layer of cutting fluid, we can safely assume a pool boiling condition. Hence the combined heat transfer is a simple function of the Nusselt number (Ne), Prandtl number (Pr), Jakob number (Ja), Bond number (Bo) and Grashof number (Gr**)**.

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Table 6. Experimental Observations.

S.N.	Nature of Cutting	DOC (MM)	Spindle Speed (RPM)	Nature of the Chip	Noise and Vibration	Temperature of Machined Surface (˚C)	Surface Roughness (µm)
1	Dry cut	2	500	Reddish discontinuous	Noisy operation	140.3	0.9 with scallop marks (feed marks)
2			1000	Bluish discontinuous	Tool vibration encountered	221.5	0.94 with scallop marks (feed marks)
3		3	500	Bluish discontinuous	Noisy operation with severe tool vibration.	178.4	1.1 scallop marks (feed marks)
4			1000	Bluish discontinuous	Noisy operation with severe tool vibration and localized welding of chip and tool were noticed	237.8	1.6 scallop marks (feed marks)
5	Cutting fluid sample 1	2	500	Continuous chips	Noisy operation, not as high as the previous case	90.2	0.57 although scallops were still present.
6			1000	Continuous chips	Tool vibration encountered	98.1	0.62 with scallops
7		3	500	Reddish discontinuous	Noisy operation with severe tool vibration.	120.4	0.65 although scallops were still present.
8			1000	Continuous chips	Noisy operation with severe tool vibration and flashes at the chip-tool interface were noticed	122.5	0.7 with scallops and feed marks
9	Cutting fluid sample 2	2	500	Continuous chips	No appreciable noise,	83.4	0.52 although scallops were still present.
10			1000	Continuous chips	No appreciable noise,	87.2	0.56, scallops present
11		3	500	Bluish discontinuous	Noise increased slightly with increasing DOC	96.5	0.58 relatively although scallops were still present.
12			1000	Bluish discontinuous	Some tool vibration encountered due to higher DOC and speed	101.4	0.61 with scallops
13	Cutting fluid sample 3	2	500	Continuous chips	Only sound due to shearing operation	60.5	0.52 although scallops were still present.
14			1000	Continuous chips	No appreciable noise	65.2	0.54 with scallops
15		3	500	Continuous chips	No appreciable noise	82.1	0.58 relatively although scallops were still present.
16			1000	Continuous chips	No appreciable noise	94.5	0.66 with scallops

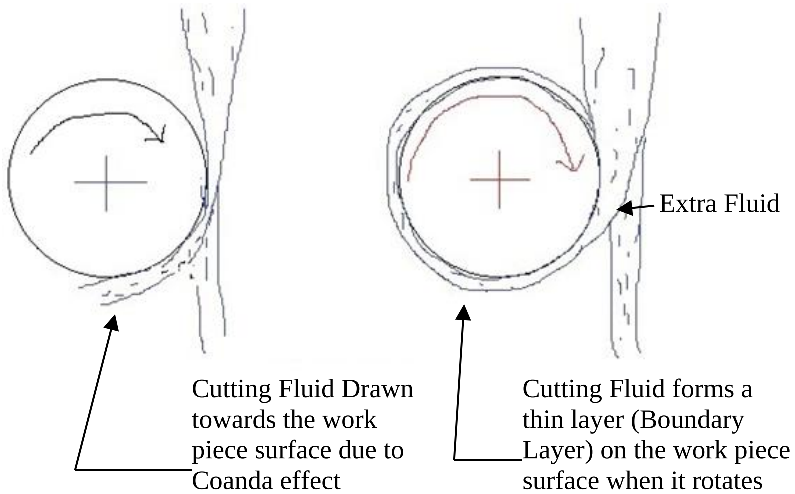

Figure 2. Cutting fluid application.

Where,

$$\mathrm{Nu} = \frac{\mathrm{hd}}{\mathrm{k}} \quad (2)$$

$$\mathrm{Pr} = \frac{\mu c_p}{\mathrm{k}} \quad (3)$$

$$\mathrm{Ja} = \frac{c_p \Delta T}{h_{fg}} \quad (4)$$

$$\mathrm{Bo} = \frac{g(\rho_l - \rho_v)d^2}{\sigma} \quad (5)$$

$$\mathrm{Gr} = \frac{\rho g(\rho_l - \rho_v)d^3}{\mu^2} \quad (6)$$

Here, c_p = sp. Heat of cutting fluid at constant pressure

ΔT = Temperature difference between temperature of application and temperature of saturation of the cutting fluid

H = Convective heat transfer coefficient

k= Coefficient of heat transfer in conduction

μ = Coefficient of viscosity or dynamic viscosity of cutting fluid

h_{fg} = Latent heat of evaporation of cutting fluid

d = Diameter of the workpiece before cutting

ρ = Average density of cutting fluid

ρ_l = Density of cutting fluid in the liquid state

σ = Surface tension of cutting fluid in the presence of air

In dimensionless groups, applying Buckingham's pi theorem we can write,

$$\mathrm{Nu} = f(\mathrm{Gr}, \mathrm{Ja}, \mathrm{Pr}, \mathrm{Bo}) \quad (7)\ [16]$$

Now the fluid has three liquid parts, water and two oils respectively (Brassica nigra and Helianthus annuus). During turning the temperature is appreciably high it is known to us (high enough to cause localized welding), so all the liquid parts will boil eventually, definitely not together due to variable boiling point. Here we can assume the Nusselt number for water, Brassica nigra and Helianthus annuus as $(Nu_d)_1$, $(Nu_d)_2$, $(Nu_d)_3$ respectively and for the air we can assume the Nusselt number on the air jacket of the workpiece is $(Nu_d)_a$. The suspended graphite particles are way less dense than the liquid parts so due to buoyant forces exerted by the liquids, the graphite flakes would hardly get into contact with the workpiece so they do not participate in extracting heat from the piece directly. Here the liquids take up the heat from workpiece as mentioned earlier, the graphite particles absorb a good part of that extracted heat from the fluid through conduction and get carried away with the continuously flowing fluid, and the remaining heat is drained to the air through convection and radiation (for very high temperature). A few assumptions were made while constructing a model equation for heat transfer-

i. The graphite particles do not go into direct contact with the workpiece surface.
ii. The net heat transfer is the sum of the heat transfer of three fluids.
iii. The heat transfer to the graphite particles is also the sum of heat transfer to the graphite particles suspended inside the three fluids, separately.
iv. If the temperature is sufficiently high, then only the radiant heat would be realizable, otherwise most of the transferred heat is by convection and then some part by conduction.

So the net overall heat transfer process which is a rather complex one can be described as

$$(Nu_d)_1+(Nu_d)_2+(Nu_d)_3=(Bi)_1+(Bi)_2+(Bi)_3+(Nu_d)_a \quad (8)$$

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Here $(Nu_d)_1$ to $(Nu_d)_3$ are defined by equation (6) and $(Nu_d)_a$ is the heat dissipated to air which is a rather natural convection, so-

$$(Nu_d)_a = f\,(Gr, Pr) \qquad (9)\ [16]$$

all the parameters like μ, k, c_p, ρ are very low for air, so evidently heat transfer associated with $(Nu_d)_a$ will be very low.

Now Bi is the Biot number associated with solid graphite particles, given by,

$$Bi = \frac{hx}{k} \qquad (10)\ [16]$$

x is any characteristic dimension of the graphite particles. One can consider the diameter, if the particles are assumed spherical; k is the thermal conductivity of graphite which has a very high order of magnitude already known to all of us, however h still pertains to the cutting fluid. Subscripts 1, 2 and 3 represent three fluids present in the suspension. Graphite has very good thermal conductivity and that is why heat transfer associated with Bi terms is the major part of heat carried away from the cutting fluid. Figure 3 shows the boiling of the water part of the cutting fluid when applied during turning.

Water which has the least boiling point starts to boil first and Helianthus annuus oil is always last in this race. When large amount of water from a given volume of the cutting fluid evaporate, it causes a vapour blanket as shown in Fig 3 but it lasts only for a fraction of second. Eventually when most of the water evaporates, the temperature of the work piece can be controlled by the mentioned oils from that point as both the oils have showed good cooling properties in numerous researches as mentioned earlier. Both the oils prevent atmospheric attacks on the nascent surface of work piece. The tool is also getting cooled due to above mentioned effect. At elevated temperature when radiation from work piece and cutting fluid is also prominent an additional term "R" need to add to equation (8) which accounts for radiation heat loss from cutting fluid. R is another dimensionless parameter given by the ratio of convective resistance to resistance to radiation.

$$(Nu_d)_1+(Nu_d)_2+(Nu_d)_3=(Bi)_1+(Bi)_{2+}(Bi)_3+(Nu_d)_a+R \qquad (15)$$

At automatic feed, when we applied the Sample 1, the end product we obtained is shown below-

Figure 4 shows the condition of the turned workpiece using Sample 1 as cutting fluid. As mentioned in Table 6, the scallops are present to some extent; however no burn mark was encountered. The Figure 5 shows the result of use of Sample 2 where it has been found that the surfaces finish is quite better, however some irregularities were still found due to workpiece misalignment during turning.

Figure 3. Boiling of cutting fluid during turning.

Figure 4. Surface morphology of EN19 specimen after applying sample-1.

Figure 5. Surface morphology of EN19 specimen after applying sample-2.

CONCLUSION

We can conclude from this experiment that using a colloidal mixture of Brassica nigra (Mustard) oil, Helianthus annuus (sunflower)oil, Water and Graphite microparticles when used as a cutting fluid, **t**he Brassica nigra (Mustard) oil due to its low specific heat provides a good cooling effect. The Helianthus annuus (sunflower) oil being a good lubricant provides a better lubrication alongside graphite which is itself a solid lubricant. The surface finish of the EN19 finished product is quite satisfactory and there is no burn mark due to overheating at variable depths of cut. The application of sample 1 mostly provided continuous chips but there was not much significant improvement in surface conditions. However sample 2 and sample 3 also resulted in continuous chips but with continuously increasing surface quality and less cutting temperature as low as 60.5˚c due to the presence of lecithin. The least surface roughness was found at 2 mm DOC and 500 rpm, which is 0.52 µm. Therefore one can conclude that a mixture of Brassica nigra, Helianthus annuus, water, graphite micro particle and lecithin could be a good cutting fluid for a specific cutting condition.

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