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Analysis of Machining Performance of En8 Using Soyabean Oil Based Cutting Fluid

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ABSTRACT: The cutting fluids are responsible for reducing heat at tool work interface, reducing the cutting force, easy chip removal, high material removal rate (MRR), lubrication improvement between tool and work piece and thereby increasing the surface finish. Good lubricating capacity, less viscosity, better heat removal rate, high heat conductivity and specific heat are the desired flow and heat transfer parameters of cutting fluids. The development of lubricants like cutting fluids traditionally has mineral oil as base fluid. This fact is related to the technical properties and the reasonable price of mineral oils. Issues of using fluids in machining related to health, environment, and manufacturing cost that need to be solved and options to reduce their use has to be developed. Hence there arises the need for an ecologically benign metal working fluid in machining operations. In this work Soyabean oil based cutting fluid is developed with different concentration of oil and water. The physical and thermal properties like viscosity, thermal conductivity, relative density and pH of these fluids were measured and the comparative study is conducted with the respective properties of mineral oil based cutting fluid. A comparative study of Wet machining using pure soyabean oil, soyabean oil based fluids and Mineral oil based fluid were conducted by taking EN-8 steel as workpiece material on a CNC Turning Centre. The experimental study was conducted in order to find out the performance of developed fluid during machining and to compare it with mineral oil based cutting fluid and with dry machining.

I.INTRODUCTION

The machining processes have an important place in the traditional production industry. In metal cutting process, the condition of the cutting tools plays a significant role in achieving consistent quality and controlling the overall cost of manufacturing. During machining process, friction between work piece-cutting tool and cutting tool-chip interfaces cause high temperature on cutting tool and work piece. The heat generation becomes more intensified in machining of hard materials because the machining process requires more energy than that in cutting a low strength material. As a result, the cutting temperatures in the tool and the work-piece rise significantly which in turn cause in increased cutting forces, dimensional inaccuracy of the product and shorter tool life. Up to this moment, completely dry cutting is not suitable for many machining processes. In spite of the lubrication purposes cutting fluids are necessary for the prevention of the sticking of the chips to the tool as well as the tool breakage.

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II. RELATED WORK

In order to carry out the project work, literatures related to metal working fluids, vegetable oil based cutting fluids, properties of cutting fluids, turning operation, development of emulsion, surface roughness, tool work interface temperature has been studied. Findings from some of the main literatures are discussed below.

[1] **W. Belluco and L.DeChiffre** analyzed the performance of six cutting fluids of which five of them are vegetable based cutting fluids. The tool lift, drilling force and chip tangling are taken as testing parameters. The test specimen is AISI316L plates. A load cell is used for measuring cutting force. The chip tangling is also measured after each cycle. Cutting fluid used were mineral oil based commercial oil, vegetable oil based commercial oil, four different combinations of rapeseed oil are ester oil in different form ie the meadow form oil, mild duty oil , meadow form and mild duty oil, general purpose oil etc. From the result it was obtained that the tool wear and failure was similar in all six fluids. The result shows that the tool life measure obtained by all five combinations of vegetable oil produced better tool life. But the cutting thrust was almost equal with all six fluids. The corner wear obtained is also lower for the vegetable oil based cutting fluids. The corner wear for mineral oil used is obtained as 300micrometer whereas the rapeseed as ester oil it is found out 150micrometer. Overall from the results as study the best performance obtained is about 177% increasing tool life and 7% reduction in trust force, which was obtained in vegetable oil than the mineral oil. It proves that the vegetable oil based fluid is a good alternative for mineral oil based fluids.

[2] **J.F.G.Oliveira and S.M.Alves** developed an environmental friendly fluid for CBN grinding. The intention was to develop a fluid based on water.

The reaction of the grinding wheel with water was checked experimentally at two conditions - at normal temperature and at 873K. From the experiment it was obtained that the chance for chemical reaction of CBN grinding wheel with water is minimum. For the study new cutting fluid were produced by mixing castor oil(40%),water(35%),bactericide(5%),anti-corrosive agent(15%)and emulsifying agent which is a polyglycol of synthetic ester(5%). The new vegetable oil based grinding fluid showed good results in grinding test similar to one that obtained with neat oil. When new cutting fluid diluted at 45% was used the wheel wear, grinding force and surface roughness where also reduced.

[3] **Saete Martins Alves** et al conducted a study for the development of a new concept of grinding fluid to be applied in CBN grinding processes. Water and vegetable oil combination used in production of cutting fluid. The roughness and wheel wear was used to evaluate the grinding operation in order to find out the performance of new cutting fluid. In order to find out best work condition different dilutions were also tested. Materials used in formulation of cutting fluid are sulphonated castor oil 80%, water, bacterial resistance derived from triasin anticorrosive. The wheel wear and work piece roughness were reduced by using new cutting fluid.

[4] **Aldo Braghini Junior** et al investigated the tool wear mechanism for an end milling operation of a precipitation hardened martensitic stainless steel under four different cooling and lubrication conditions. The cooling condition used were flood of vegetable oil based emulsion, low flow of neat vegetable oil, application of neat vegetable oil with compressed air and dry cutting. As a result the longest tool life was obtained in low flow of neat vegetable oil and next to the neat vegetable oil under MQL. Flood cutting fluid supply's performance wasworst.

III. VEGETABLE OIL BASED CUTTING FLUIDS

Vegetable oils consists of triacylglycerides (triglycerides) which are glycerol molecules with three long chain fatty acids attached at the hydroxyl group via ester linkages. The fatty acids in vegetable oil triglycerides are all of similar length between 14 and 22 carbons long. But their unsaturation levels vary. The triglycerides structure of vegetable oils provides desirable properties of lubricant. Long, polar fatty acid provides high strength lubricant films which interact strongly with metal surfaces and reduces both friction and wear. Vegetable oil have a higher viscosity index. However, thermal and oxidation stability of vegetable oils are limited. Vegetable oils perform better than the other oils and the reasons are described as follow:

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- Vegetable oil has good lubricity properties. The highly lubricating properties of vegetable oil are made possible by the fundamental composition of the vegetable oil molecules, as well as the chemical structure of the oil itself. Its properties are the direct result of the vegetable oil's smart molecules. These molecules are long, heavy and dipolar in nature; that is, the ends of the molecules having opposing electrical charges. Vegetable oils carry slight polar charge but mineral oils have no charge. This polar charge draws vegetable oil molecule to a metallic surface like little magnets; therefore, vegetable oils adhere to a metal surface more tightly than mineral oils. Dense, homogenous alignment of vegetable oil molecules creates a thick, strong and durable film layer of lubricant. This lubricating film gives the vegetable oil a greater capacity to absorb pressure. In contrast, the molecules of mineral oils are intrinsically non-polar. They form a random alignment along a metal surface, which provides a weaker layer of lubrication. Consequently, vegetable oil makes a better lubrication.
- Vegetable oil has a higher flash point, which reduce smoke formation and fire hazard. Higher flash point value allows using the cutting fluid in high temperature cutting conditions.
- Viscosity is another oil property that has an important effect on machining productivity. Vegetable oil has a high natural viscosity as the machining temperature increases. The viscosity of vegetable oils drops more slowly than that of mineral oils. As the temperature falls, vegetable oils remain more fluid than mineral oils, facilitating quicker drainage from chip and work pieces. The higher viscosity index of vegetable oils ensures that vegetable oils will provide more stable lubricity across the operating temperature range.
- Vegetable oil molecules are quite homogenous in size but mineral oil molecules vary in size. Consequently, the properties of mineral oil such as viscosity, boiling temperature are more susceptible to variation.
- Vegetable oil has higher boiling point and greater molecular weight and this result in less loss from vaporization and misting.

IV. SOYABEAN OIL BASED CUTTING FLUIDS

Soyabean oils consists of triacylglycerides (triglycerides) which are glycerol molecules with three long chain fatty acids attached at the hydroxyl group via ester linkages. The triglycerides structure of Soyabean oils provides desirable properties of lubricant. Long, polar fatty acid provides high strength lubricant films which interact strongly with metal surfaces and reduces both friction and wear. Soyabean oil has a higher viscosity index.

Soyabean oil has good lubricity properties. The highly lubricating properties of soyabeanoil are made possible by the fundamental composition of the soyabeanoil molecules, as well as the chemical structure of the oil itself. Its properties are the direct result of the soyabeanoil's smart molecules. These molecules are long, heavy and dipolar in nature; that is, the ends of the molecules having opposing electrical charges. Soyabeanoil's carry slight polar charge but mineral oils have no charge. This polar charge draws soyabeanoil molecule to a metallic surface like little magnets; therefore, soyabeanoil molecules adhere to a metal surface more tightly than mineral oils. Dense, homogenous alignment of vegetable oil molecules creates a thick, strong and durable film layer of lubricant. This lubricating film gives the soyabeanoil a greater capacity to absorb pressure. In contrast, the molecules of mineral oils are intrinsically non-polar. They form a random alignment along a metal surface, which provides a weaker layer of lubrication. Consequently, soyabeanoil makes a better lubricant.

Preparation of Cutting Fluid

In this work soyabean oil is used as the base fluid for the preparation of cutting fluid. The formulation act as an oil in water emulsion. Oleic acid is an unsaturated fatty acid which is used as an emulsifying or solubilizing agent. Besides serving as an agent for improving the lubricity of the cutting fluid, it also acts as friction modifier for lowering the friction coefficient. In water soluble cutting fluids, triethanol amine is used to provide the alkalinity needed to protect against rusting and it acts as an anti-oxidant. It also controls the evaporation rate of water in cutting fluid.

Soyabean oil based concentrate was formulated by mixing soyabean oil with Oleic acid and Triethanol Amine in the ratio of 2:2:1 respectively. For preparing 1L of oil concentrate 400ml of soyabean oil was taken in beaker and 400ml of oleic acid is added slowly. The mixture was stirred thoroughly using a mechanical stirrer upto when a homogenous liquid is formed. Then 200ml of triethanol amine was added to it and stirred well so as to get a homogenous mixture.

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Thus the oil concentrate is prepared. This homogenous mixture can dissolve in water in all proportions and functions as oil in water emulsion.

Four emulsion samples were formed by varying the concentration of oil as 10%, 20%, 30% and 40%, remaining water. For preparing the emulsion the required quantity of water was taken and the water is stirred using a stirrer so that a vortex was formed. Then the oil was slowly poured into the vortex. The stirring was continued for few minute until we get a homogenous emulsion.

V. COMPARISON OF PROPERTIES OF CUTTING FLUID

The selection of cutting fluid is based on some basic properties. The basic properties which determine the selection of cutting fluid are viscosity, thermal conductivity, acidity or alkalinity, relative density etc.

1. Viscosity

Viscosity is a measure of the resistance of a fluid to deform under shear stress. Viscosity is due to the friction between neighboring particles in a fluid that are moving at different velocities. When the fluid is forced through a tube, the fluid generally moves faster near the axis and very slowly near the walls; therefore, some stress (such as a pressure difference between the two ends of the tube) is needed to overcome the friction between layers and keep the fluid moving. For the same velocity pattern, the stress required is proportional to the fluid's viscosity. A liquid's viscosity depends on the size and shape of its particles and the attractions between the particles. The dynamic (shear) viscosity of a fluid expresses its resistance to shearing flows, where adjacent layers move parallel to each other with different speeds. It can be defined through the idealized situation known as a Couette flow, where a layer of fluid is trapped between two horizontal plates, one fixed and one moving horizontally at constant speed u .

2.Measurement of Viscosity

The viscosity of the cutting fluids can be measured with the help of Brookfield Rotational Viscometer (model: DV2TLVCJ0) supplied by Brookfield Engineering Laboratories. The water bath found along with the viscometer can be used to study the viscosity variation of the fluid with temperature. It is a precise torque meter which is driven at discrete rotational speeds. The torque measuring system, which consists of a calibrated beryllium copper spring connecting the drive mechanism to a rotating cone, senses the resistance to rotation caused by the presence of sample fluid between the cone and a stationary flat plate. The resistance to the rotation of the cone produces a torque that is proportional to the shear stress in the fluid. This reading is easily converted to absolute centipoises units (mPa.s) from pre-calculated range charts. Alternatively, viscosity can be calculated from the known geometric constants of the cone, the rate of rotation, and the stress related torque. The correct relative position of cone and plate is obtained by following a simple mechanical procedure without the need for external gauges or supplementary instrumentation.

The stationary plate forms the bottom of a sample cup which can be removed, filled with 0.5 ml to 2.0 ml of sample fluid (depending on cone in use), and remounted without disturbing the calibration. The sample cup is jacketed and has tube fittings for connection to a constant temperature circulating bath. The system is accurate to within +/-1.0% of full scale range. Reproducibility is within +/-2%. Working temperature range is from 0°C to 100°C.

The viscometer has a cup in which the test fluid in an amount of 1 ml is poured and a spindle which is selected according to the viscosity range. Here spindle used is CP-40Z which is used for sample in the viscosity range of 0.3 to 1028 cP. As the spindle is rotated, the viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. The spindle speeds available with this viscometer is from 0 to 200 rpm. The value of viscosity at the speed at which maximum torque obtained is taken. Desired temperature can be provided to the fluid in the viscometer by connecting the sample cup inlet/outlet ports to the water bath inlet and outlet and setting the bath to the desired test temperature. When the reading of temperature in the viscometer and the water bath becomes equal, the viscosity is measured.

It is seen that the mineral oil based cutting fluid is having the least value of viscosity at three different temperatures. Soyabean oil based cutting fluid with 10% and 20% oil concentration is having comparable viscosity with mineral oil based cutting fluid. But other two combination of soyabean oil based cutting fluid is having higher viscosity when

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compared with mineral oil based cutting fluid. The viscosity of cutting fluid increases the lubrication effect but it reduces the flowability of cutting fluid. So a moderate viscosity is desirable for a cutting fluid. The viscosity of all fluids decreases with increase in temperature.

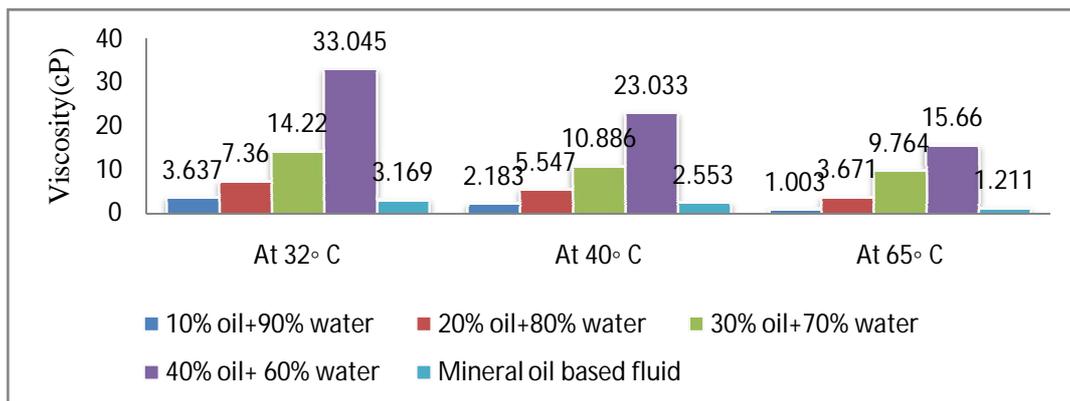


Fig 1: Comparison of Viscosity at Different Temperatures

VI. THERMAL CONDUCTIVITY

Thermal conduction is a very important and a major topic in the study of heat transfer. Conduction is the transfer of energy from energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the collision and diffusion of the molecules during their random motion. The rate of heat conduction is proportional to the area and the temperature difference, and inversely proportional to the thickness of the material. The constant of proportionality is the thermal conductivity. Thus, the thermal conductivity, k , of a material is defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference. Therefore, it is a measure of how fast heat will flow in the material. A large value for thermal conductivity indicates that the material is a good conductor, while a low value indicates that the material is a poor conductor or a good insulator.

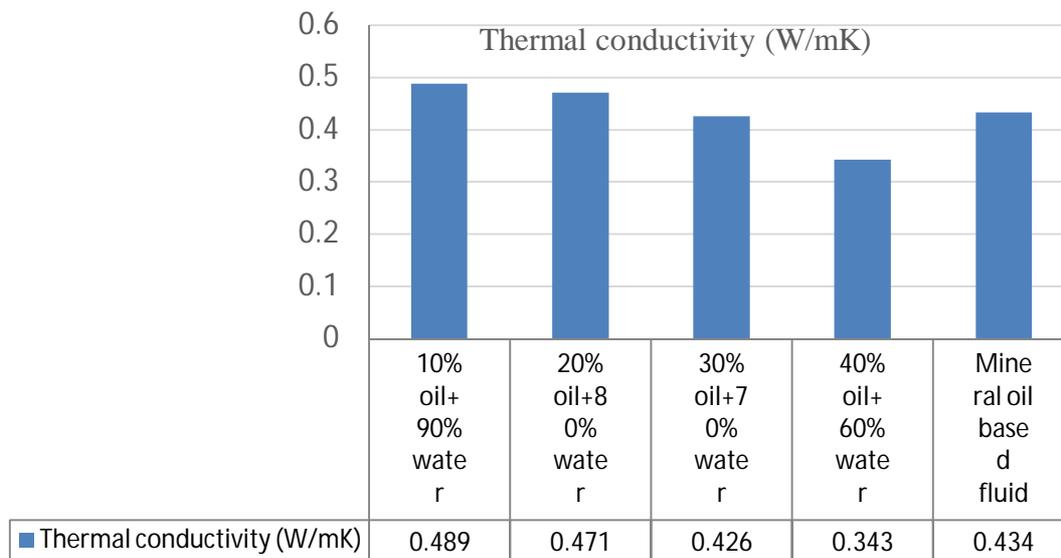


Fig 2: Thermal conductivity

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The thermal conductivity of cutting fluids considered are shown in the figure 4.9 Among these cutting fluids the soyabean oil based cutting fluid with 10% oil concentration gives maximum thermal conductivity. The soyabean oil based cutting fluid with 40% oil concentration is having least thermal conductivity which is less than thermal conductivity of mineral oil based cutting fluid. Cutting fluid with 30% oil concentration is also having lesser thermal conductivity when compared with mineral oil based cutting fluid. Other two cutting fluids developed from soyabean oil are having more thermal conductivity than mineral oil based cutting fluid. So the cooling effect that can be produced by these fluids is more than that of mineral oil based cutting fluid. As the water content in emulsion increases the thermal conductivity of emulsion also increases which can be seen from the figure.

VII. RELATIVE DENSITY

Relative density is the ratio of the density of liquid to the density of water at same condition of temperature and pressure. The density of liquid is required to calculate flow rates and for the conversion of kinematic viscosity to dynamic viscosity. A good cutting fluid should always possess good flow ability as well as good lubricating property. For this the relative density should not be so high or so low. Most mineral oils have the viscosity in the range between 0.85 to 0.95.

In order to measure the relative density the weight of 25ml of water is measured using a digital weight meter then the weight of 25ml of required sample is also taken. Then by taking the ratio between weights of fluid to weight of water the relative density of required fluid sample is obtained.

$$RELATIVE\ DENSITY = \frac{WEIGHT\ OF\ 25ml\ OF\ TEST\ FLUID}{WEIGHT\ OF\ 25ml\ OF\ WATER}$$

The relative density of different cutting fluid are shown in the figure 4.11 .The relative density of soyabean oil based fluid having 10% oil concentration is almost equal to 1. Soyabean oil based cutting fluid with 10% and 20% oil concentration is having more relative density than mineral oil based cutting fluid. Other two fluids are having lesser relative density. The increase in oil content decreases the relative density of emulsion.

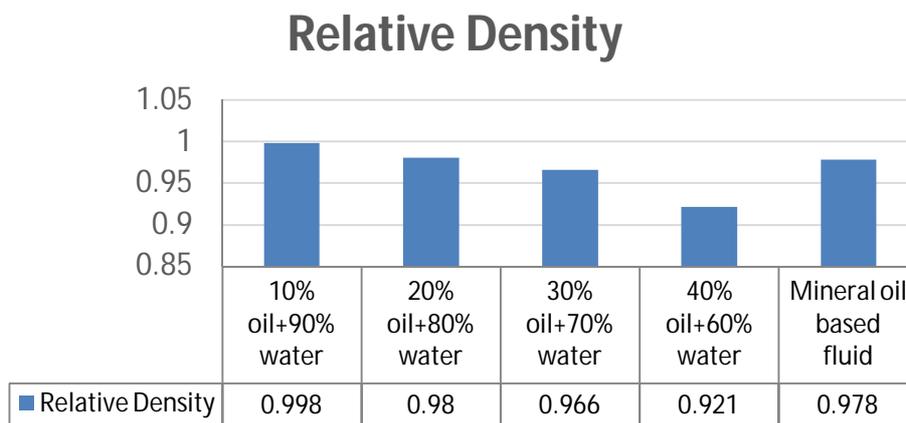


Fig 3: Relative Density

VII. ACIDITY AND ALKALINITY

The nature of cutting fluid in case of acidity also determines the selection of cutting fluid. The acidity or alkalinity of cutting fluid can be determined by using a pH meter. The pH scale shows a fluid's acidity or alkalinity. The fluid having a value less than 7 during pH test is acidic in nature and pH value greater than seven is basic in nature. Pure water is having a pH value of seven.

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In case of cutting fluid the fluid is commonly made basic. The acidity of cutting fluid will produce a chance of combustion during machining. So cutting fluids are commonly basic in nature. Basic nature of the cutting fluid also protects the work piece from corrosion or oxidation and it helps in stabilizing the emulsion.

The acidity or alkalinity of the fluid samples is measured by using a digital pH meter. A digital pH meter is a scientific instrument that measures the hydrogen-ion concentration (or pH) in a solution, indicating its acidity or alkalinity. The pH meter measures the difference in electrical potential between a pH electrode and a reference electrode. It usually has a glass electrode plus a calomel reference, or a combination electrode.

Basic potentiometric pH meters simply measure the voltage between two electrodes and display the result converted into the corresponding pH value. They comprise a simple electronic amplifier and a pair of probes, or a combination probe, and some form of display calibrated in pH. The probe is the key part: it is a rod-like structure usually made of glass, with a bulb containing the sensor at the bottom. Frequent calibration with solutions of known pH, perhaps before each use, ensures the best accuracy. To measure the pH of a solution, the probe is dipped into it.

For very precise work the pH meter should be calibrated before each measurement. For normal use calibration should be performed at the beginning of each day. The reason for this is that the glass electrode does not give a reproducible e.m.f. over longer periods of time.

After each single measurement, the probe is rinsed with distilled water or deionized water to remove any traces of the solution being measured, blotted with a scientific wipe to absorb any remaining water which could dilute the sample and thus alter the reading, and then quickly immersed in a solution suitable for storage of the particular probe type. The pH of different cutting fluid are shown in figure 4.13 the fluids with pH value less than 7 is acidic in nature and pH value more than seven is basic in nature. All the soyabean oil based cutting fluids are having more pH than mineral oil based cutting fluid and all are basic in nature. Basic nature is the desirable property of cutting fluid during selection. The pH of fluid increases with increase in oil concentration.

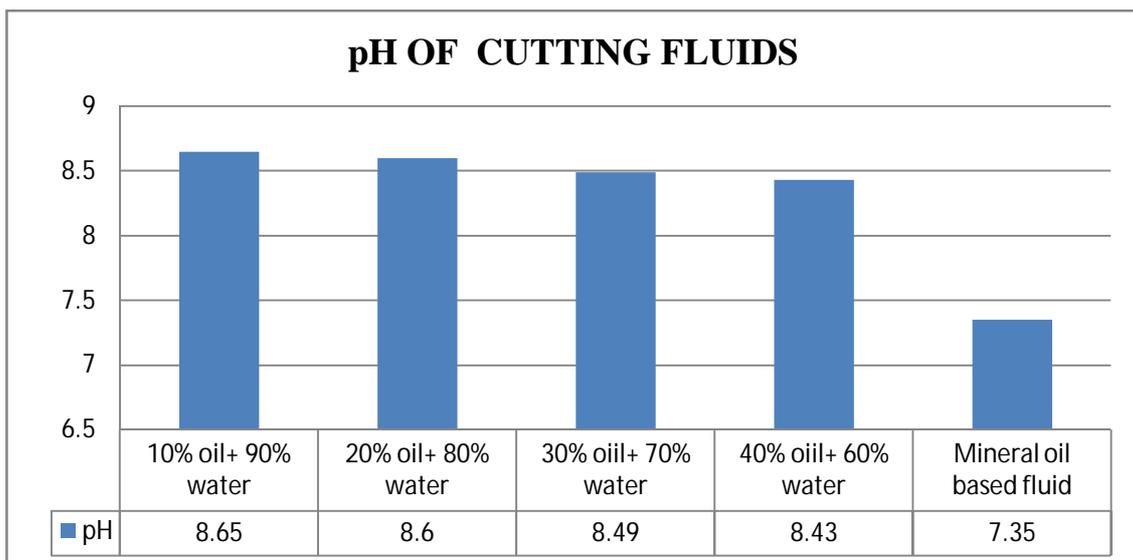


Fig 4: pH of Cutting Fluid

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IX. EXPERIMENTAL DATA

Trial No.	Speed	Feed	Type of oil	Roughness average(Ra)	Temperature
	m/min	mm/rev		5µm	°c
1	125	0.05	Mineral oil	2.354	37.5
2	125	0.05	Soyabean oil	2.594	46.2
3	125	0.05	10% oil	2.548	34.2
4	125	0.05	15% oil	2.899	34.5
5	125	0.05	20% oil	2.681	35.1
6	125	0.05	25% oil	1.911	36.8
7	125	0.05	30% oil	1.848	39.6
8	800	0.175	Mineral oil	3.549	39.3
9	800	0.175	Soyabean oil	2.095	47.8
10	800	0.175	10% oil	3.374	34.8
11	800	0.175	15% oil	3.674	35.2
12	800	0.175	20% oil	2.457	35.6
13	800	0.175	25% oil	2.092	37.8
14	800	0.175	30% oil	2.094	41.2

Graphs are plotted according to the data collected during the turning operation of EN 8 material. The graphical data are used for final comparison and hence to arrive at the final conclusion.

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X. RESULT AND DISCUSSIONS

I. COMPARISON OF Ra WITH RESPECT TO TYPE OF CUTTING FLUID

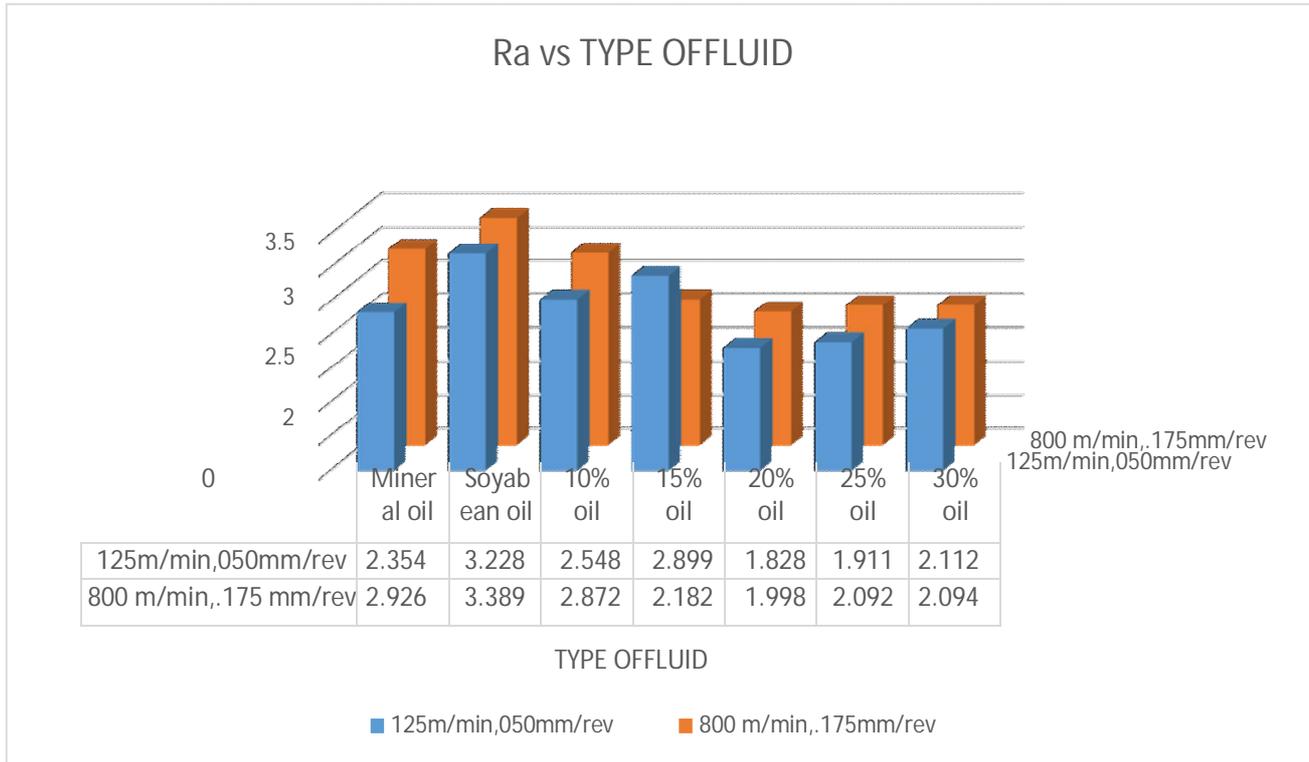


Fig 5: Comparison of Ra with respect to type of Cutting Fluid

Variation of roughness average with respect to type of cutting fluid at two different cutting conditions is shown in the above figure. From the graph it is evident that cutting fluid with 20% oil content shows best result during both the cutting conditions. Machining with pure soyabean oil shows least surface finish in both cutting conditions since the viscosity of pure soyabean oil is far greater than other six cutting fluids which reduces the penetration to the gap between the tool and work piece. All the cutting fluids prepared from soyabean oil show better results than conventional mineral oil based cutting fluids.

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XI. COMPARISON OF TEMPERATURE WITH RESPECT TO TYPE OF CUTTINGFLUID

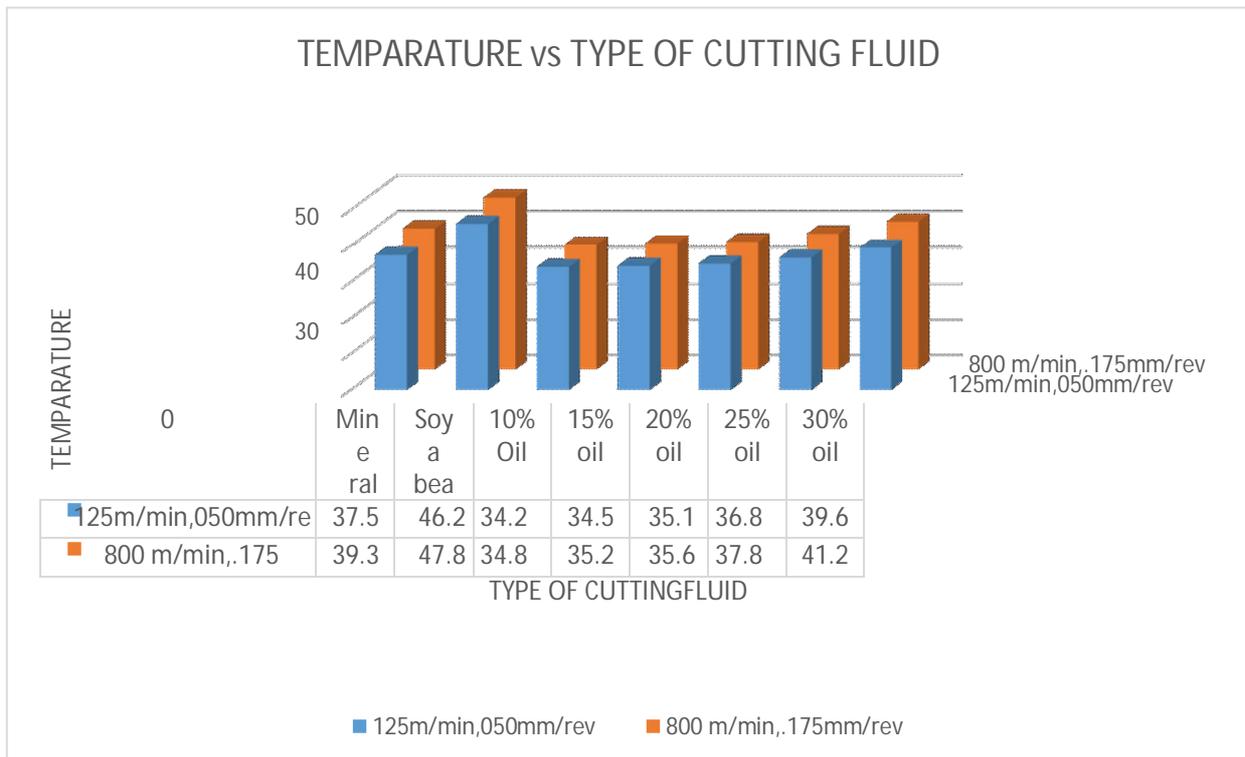


Fig 6: Comparison of temperature with respect to type of Cutting Fluid

The graph shows the variation of temperature with respect to type of cutting fluid at two different cutting conditions. The temperature at tool work interface is maximum for machining with soyabean oil. As the water content in the emulsion increases the thermal conductivity also increases so the cooling effect will be maximum for cutting fluid with minimum oil content here fluid with 10% oil content provided better cooling effect and the cutting fluid with 15% and 20% oil content is also having a comparable cooling effect with respect to cutting fluid with 10% content and is superior to conventional mineral based cuttingfluid. During machining more importance is given for obtaining required surface finish and minimizing the surface temperature in order to reduce thetool

XII. CONCLUSIONS

Soyabean oil based emulsion prepared by mixing oil and water with the help of a suitable emulsifying agent the main properties of the cutting fluid like viscosity, thermal conductivity, relative density and pH is also measured for each concentration of soyabean oil in water emulsion and is also compared with commonly used mineral oil based cutting fluid. The experimental study was carried out on a CNC lathe for turning operation of EN 19 Steel. Cutting speed, feed rate and type of cutting fluid are as selected as process parameters by keeping constant depth of cut. Surface finish and tool work interface temperature were selected as responses.. The main findings of the work are,

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- The study shows that the soyabean oil based cutting fluid with 20% oil concentration shows better performance than other fluid during machining. All the developed cutting fluid except fluid with the soyabean oil based cutting fluid with 40% oil concentration shows a comparable or better performance with mineral oil based cutting fluid.
- Machining using the soyabean oil based cutting fluid with cutting fluid with 10% and 20% oil concentration showed lesser value of temperature at tool work interface.
- The viscosity values of the soyabean oil based cutting fluid with cutting fluid with 10% and 20% oil concentrations gives comparable result with mineral based cutting fluid. But the value of other two concentrations was more than that of mineral oil based cutting fluid. Since concentration of oil in emulsion increases the viscosity of emulsion also increases.
- The thermal conductivity of the soyabean oil based cutting fluid with cutting fluid with 10% oil concentration is superior to all other fluids. The thermal conductivity of fluid increases with decrease in oil concentration in an emulsion.
- All the cutting fluid developed is basic in nature which a desirable property of cutting fluid.
- Overall cutting fluid with 20% oil concentration is having better performance than all other varieties. Since both surface roughness and tool work interface is minimum. The reduced surface roughness and tool wear is due to the combined effect of both viscosity and thermal conductivity. As the oil content in emulsion increases viscosity increases and hence the lubrication increases but the thermal conductivity decreases. The water content in emulsion enhances thermal conductivity. Considering these facts in both aspects cutting fluid with 20% oil concentration shows better results.
- The soyabean oil based cutting fluid can be utilized as a suitable and possible alternative for mineral oil based cutting fluid considering the environmental issues and wastage accumulation.

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