International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

Effects of Vegetable Oil Based Cutting Fluid in Turning AISI1040 Steel by Uncoated Carbide Tool

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Abstract—Turning of medium carbon steel by uncoated carbide tool has been faced several adverse aspect of technical, economical, safety and health of the worker and mostly environmental by using conventional cutting fluid. To minimize the cutting temperature, these issues had been dedicated and sacrificed over decades. This work summarizes to observe the effects of environmental friendly vegetable oil in turning AISI-1040 steel. Vegetable oils are being investigated to serve as a possible replacement for non-biodegradable mineral oils, which are currently being used as base oil in cutting fluids during machining processes. In this present study, the performance of olive oil was compared with that of dry machining operation of medium carbon steel. Temperature of the workpieces as well as their chip formation rates using the vegetable oil as cutting fluids under different cutting speed (rev/min), feed rate (mm/rev) and depth of cut (mm) were compared with that of mineral dry machining.

Index Terms— Chip-Tool Interface, Cutting Parameter, MQF, MRR, Tool-Work Thermocouple, Turning Operation, Uncoated Carbide, Vegetable Oil

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1 INTRODUCTION

Turning isa form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving more or less linearly while the work piece rotates. The tool's axes of movementmaybe literally a straight line, or they may be along some set of curves or angles, but they are essentially linear. Usually the term "turning" is reserved for the generation of external surfaces by this cutting action, whereas this same essential cutting action when applied to internal surfaces is called "boring". The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cuttingtool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape. Turning is used to produce rotational, typically axis-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces.The main process variables in this case are the cutting speed, the feed rate, and the depth of cut. Cutting speed is either given as the rotation velocity of the work piece or as the linear tangential velocity of the workpiece at the tip of the cutting tool, feed rate is defined as the linear distance that tool traverses during one rotation of the work piece, and cutting depth is the radial engagement between the cutting tool and the work piece.

To minimize the use of cutting fluid, two techniques have been intensively experimented: cutting without any fluid and cutting with a minimum quantity of fluid (MQF), where a very low amount of fluid is pulverized in a flow of compressed air.When MQF is used, the steam, the mist and the oil smoke are considered undesirable sub-products, since they cause an increase of air pollution. In Germany, the maximum concentration of pollutant in the air in mist form is 5mg/m3 and when the pollution is in steam oil form the limit is 20 mg/m3 [16]. But this could be far more advantageous than dealing with problems of discarding used cutting fluids.

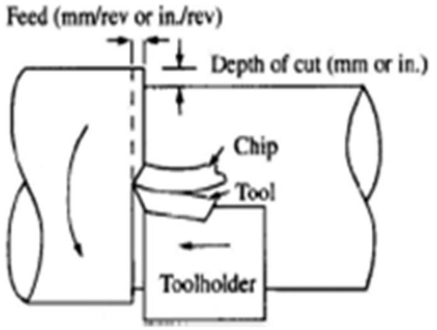


Fig.1.Traditional Turning Process [17]

2 LITERATURE REVIEW

2.1Effects and Control of Cutting Temperature

Cutting temperature is not constant through the tool, chip and work piece. The temperature field in the cutting zones is shown in Fig. 2. It is observed, that the maximum temperature is developed not on the very cutting edge, but at the tool rake some distance away from the cutting edge. The primary aim of applying cutting fluids during machining is to eliminate, overcome or at least reduce the heat generation effect, friction and corrosion of both the tool and the work piece [7]. Their resulting positive effects include prompt heat removal, lubrication on the chip-tool interface and chip removal by constantly cleaning the machined zone [9]. Heat is generated and built-up at the region between the tool's rake and/or flank faces and the work piece by the action of rubbing together of the tool and work piece. This may lead to generation of tensile residual stresses and micro cracks at the material surface [15]. Frictional energy develops between the duo which leads to rapid tool wear and reduction in tool life.Generally, suitable cutting fluid is employed to reduce this problem through cooling and lubrication at the cutting zone. But it has been experienced [13] that lubrication is effective at low speeds when it is accomplished by diffusion through the work piece and by forming solid boundary layers from the extreme pressure additives, but at high speeds no sufficient lubrication effect is evident. The ineffectiveness of lubrication of the cutting fluid at high speed machining is attributed [14] to the inability of the cutting fluid to reach the actual cutting zone and particularly at the chip-tool interface due to bulk or plastic contact at high cutting speed.

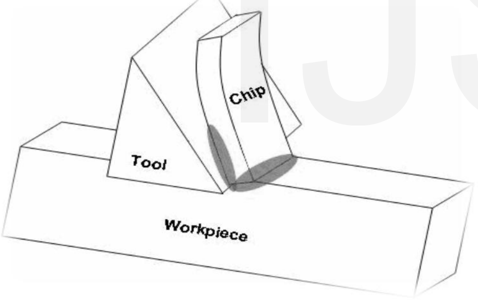


Fig.2. Region of Heat Generation during Machning

2.2 Adverse Effects of Conventional Cutting Fluid

Machado and Wallbank[12] conducted experiments on turning medium carbon steel (AISI 1040) using a venture to mix compressed air with small quantities of a liquid lubricant, water or soluble oil. The mixture was directed onto the rake face of a carbide tool against the chip flow direction. The application of a mixture of air and soluble oil was able to reduce the consumption of cutting fluid, but it promoted a mist in the environment with problems of odors, bacteria and fungi growth of the overhead flooding system.the environmental challenges of managing a used cutting fluid waste stream, cutting fluids also introduce several health/safety concerns. The National Institute for Occupational Safety and Health (NIOSH) estimates that 1.2 million workers involved in machining, forming, and other metalworking operations are exposed to metalworking fluids annually [10]. Dermal exposure to these fluids represents a health concern, as does the inhalation of airborne fluid particulate. The application of cutting fluids within a machining operation often produces an airborne mist, and medical evidence has linked worker exposure to cutting fluid mist with respiratory ailments and several types of cancer [11]. This makes the use of cutting fluids a health issue with the potential of both long and short-term consequences.

3 TOOL WORK THERMOCOUPLE TECHNIQUE FOR TEMPERATURE MEASUREMENT

Temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Due to the high shear and friction energies dissipated during a machining operation the temperature in the primary and secondary shear zones are usually very high, hence affect the shear deformation and tool wear. In a single point cutting, heat is generated at three different zones i.e. primary shear zone, chip tool interface and the tool work-piece interface. Therefore, it is desirable to determine the temperatures of the tool and chip interface to analyze or control the process. To measure the tool temperature at the tool chip interface many experimental methods have been developed over the past century. Since at the interface there is a moving contact between the tool and chip, experimental techniques such as standard pre calibrated thermocouples cannot be used to measure the interface temperature. Much research has been undertaken into measuring the temperatures generated during cutting operations.

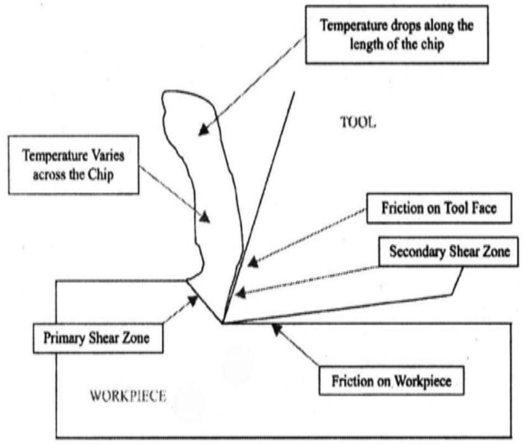


Fig.3. Heat generated by chip formationin tool-work thermocouple.

The main techniques used to evaluate the cutting temperature during machining are tool-chip thermocouple, embedded thermocouple, and thermal radiation. The thermocouple methods are based on the thermocouple principle that states that two contacting materials produce an electromotive force (emf) due to difference in temperatures of cold and hot junctions. The validity of assumptions made and possible source of errors in different experimental technique. In order to measure the cutting edge temperature using a thermocouple two different methods can be used to fix the hot junction close to the cutting edge. In the first method, the thermocouple is clamped in a recess, which is ground off the rake face of the tool to locate the hot junction as close as possible to the cutting edge. In the second method, the thermocouple is inserted in a precisely grooved carbide chip breaker, which is clamped mechanically on the tool such that the hot junction is at the same distance as in the first method. Comparing results obtained by the two methods showed that both methods gave the same results. Therefore it was suggested that the second method is better since the recess in the cutting tool would change the temperature distribution along the rake face. In addition the second method is considered easier to implement. In this paper the tool-work thermo couple technique was used to measure the chip-tool interface temperature during machining of AISI 1040 steel alloy. And we measure this by millivoltmeter vs. thermometer.

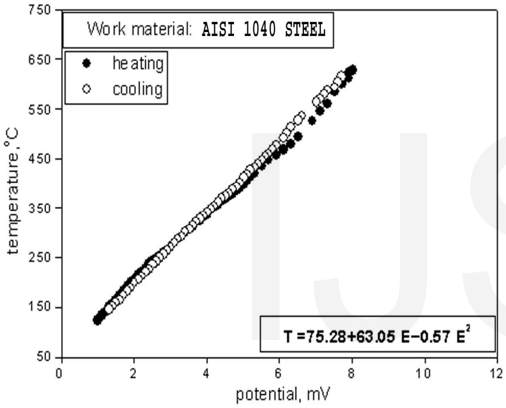


Fig.4.Temperature calibration curve for uncoated carbide and AISI1040 steel.

4 EXPERIMENTAL INVESTIGATIONS

4.1 Experimental Procedure & Condition

The high cutting temperature generated during machining not only reduces tool life but also impairs the product quality. The temperature becomes more intensive when cutting velocity and feed are increased for higher MRR and the work materials are relatively difficult to machine for their high strength, harden ability and lesser thermal conductivity. Cutting fluids are widely used to reduce the cutting temperature. Vegetable oils are nontoxic to the environment and biologically inert and do not produce significant organic disease and toxic effect. A vegetable oil is a triglyceride extracted from a plant. The term "vegetable oil" can be narrowly defined as referring only to substances that are liquid at room temperature, or broadly defined without regard to a substance's state of matter at a given temperature. For this reason, vegetable oils that are solid at room temperature are sometimes called vegetable fats. Vegetable oils are composed of triglycerides, as contrasted with waxes which lack glycerin in their structure. Although many plant parts may yield oil, in commercial practice, oil is extracted primarily from seeds.Molecules, being long, heavy and dipolar in nature create a dense homogeneous strong lubricating film that gives the vegetable oil a greater capacity to absorb pressure.

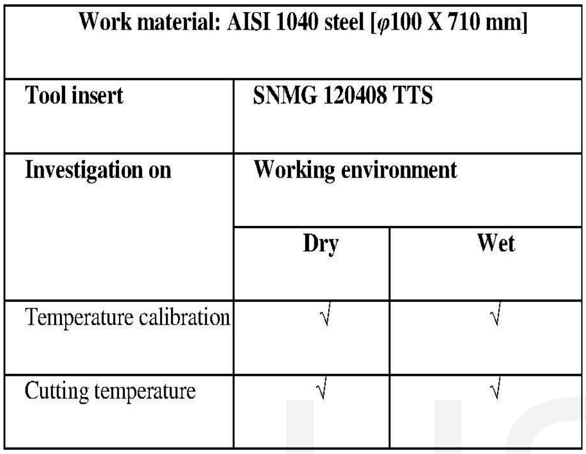
TABLE 1
CHARACTERISTICS OF THE USED STEEL

Work material	Chemical composition [wt %]	Applications
AISI 1040 Steel 257	Iron, F 98.6-99, Manganese, Mn 0.60-0.90, Carbon, C 0.370-0.440, Sulfur, S ≤ 0.050, Phosphorous, P ≤ 0.040	Shafts & crank shafts Cold headed parts High strength studs and bolts Couplings etc.

Fig.5.Photographic view of the experimental set-up.

In this regard, it has already been observed through previous research that proper application of vegetable oil may play vital role in providing not only environment friendliness but also some techno-economic benefits.The machining tests have been carried out by straight turning of AISI 1040 steel in a rigid and reasonably powerful lathe (3.5kW, France) by standard uncoated carbide inserts at different cutting velocities (Vc), rpm(N) and feeds (So) under dry, wet conditions. Considering common interest and time constraint only uncoated carbide inserts of grade have been used for the present work. Wide scope will remain for further study on MQL effect in machining steels by coated carbides and exotic materials by high performance ceramics, CBN and diamond.Effectiveness of cooling and the related benefits depend on how closely the vegetable oil can reach the chip-tool and the work-tool interfaces where, apart from the primary shear zone, heat is generated.

TABLE 2
MACHINING RESPONSES INVESTIGATED



Work material: AISI 1040 steel [φ100 X 710 mm]		
Tool insert	SNMG 120408 TTS	
Investigation on	Working environment	
	Dry	Wet
Temperature calibration	√	√
Cutting temperature	√	√

The tool geometry is reasonably expected to play significant role on such cooling effectiveness. Keeping this view a standard tool configuration namely SNMG 120408[SANDVICK] has been undertaken for the present investigation. The inserts were clamped in a PSBNR 2525 M12 type tool holder.The positioning of the dropper that contains vegetable oil with respect to the cutting insert has been settled after a number of trials. During experimentation, the thin but high velocity stream of vegetable oil was directed along the auxiliary cutting edge of the insert, so that the coolant reaches as close to the chip-tool and the work-tool interfaces as possible and cools the aforementioned interfaces and the auxiliary flank effectively as well.

The machining responses that have been studied and evaluated for assessing the machine ability characteristics of the steel specimens under both dry and wet (vegetable oil) conditions are indicated in Table 2. It has already been reported [2], [3], [4] that use of conventional cutting fluids (wet machining) does not serve the desired purpose in machining steels by carbides, rather reduces tool life and often may cause premature failure of the insert by brittle fracture. The conditions under which the machining tests have been carried out are briefly given in Table 3.

TABLE 3
EXPERIMENTAL CONDITIONS

Machine tool	Lathe Machine [France], 3.5kW	
Work material	AISI 1040 steel [φ100 X 710 mm]	
Cutting tool[insert]		
	Uncoated Carbide, [P-30 grade], Sandvick	
Cutting insert	SNMG 120408	
Tool holder	PSBNR 2525M12[ISO specification]	
Working tool geometry	Inclination angle	: -6°
	Orthogonal rake angle	: -6°
	Orthogonal clearance angle	: 6°
	Auxiliary cutting edge angle	: 15°
	Principal cutting edge angle	: 75°
	Nose radius	: 0. 8 mm
Process parameters		
RPM,N	132,170,210,260rpm	
Feed rate, S_o	0.10, 0.12, 0.14 and 0.16 mm/rev	
Depth of cut, t	1.0 mm	
Environment	Dry and Wet condition.	

^{a}RPM = rotation per minute

4.2 Calibration of Tool-Work Thermocoupke

Tool-work thermocouple can be calibrated in several ways, which include (a) furnace calibration[1], [8] (b) resistance heating [6] (c) embedded silver bit technique [5].For the present investigation, the calibration of the work-tool thermocouple has been carried out by external flame heating. The work-tool thermocouple junction was constructed using a long continuous chip of the concerned work-material and a tungsten carbide insert to be used in actual cutting. To avoid generation of parasitic emf, a long carbide rod was used to extend the insert.

The emf generated by the hot junction of the chip-tool was monitored by a digital multimeter [model: DH 334, Philips]. Fig.6shows the photographic view tool-work thermocouple set up. Table 4 shows the experimented value that was obtained by turning AISI-1040 steel both in dry and wet (vegetable oil) condition.

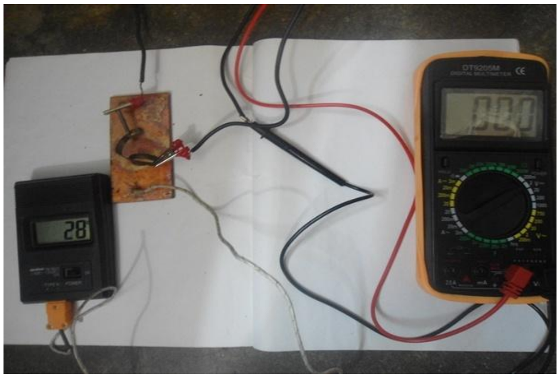


Fig. 6.Photographic view of tool-work thermocouple set up.

During machining any ductile materials, heat is generated at the (a) primary deformation zone due to shear and plastic deformation (b) chip-tool interface due to secondary deformation and sliding (c) work-tool interfaces due to rubbing. All such heat sources produce maximum temperature at the chip-tool interface, which substantially influence the chip formation mode, cutting forces and tool life. Therefore, attempts are made to reduce this detrimental cutting temperature.

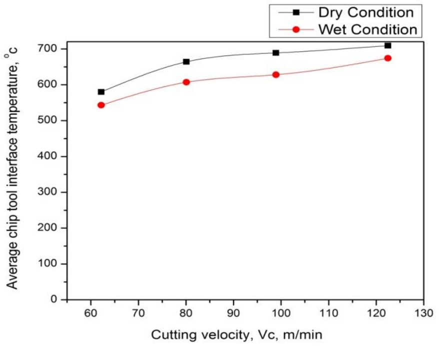


Fig. 7.Variation in θavg.withV_c and S_0in turning steel by SNMG insert under dry and wet condition at 0.10 feed rate.

TABLE 4

THE EXPERIMENTED VALUE THAT WAS OBTAINED BY TURNING AISI-1040 STEELBOTH IN DRY AND WET (VEGETABLE OIL) CONDITION

So	N	Vc	mV(dry condition)	Temp(dry condition)	mV(wet condition)	Temp(wet condition)
0.10	132	62.172	8.7	580	8	543
	170	80.07	10.3	664	9.2	607
	210	98.91	10.8	689	9.3	628
	260	122.46	11.2	709	10.5	674
0.12	132	62.172	9.3	612	8.6	575
	170	80.07	10.5	674	9.5	623
	210	98.91	11.3	714	10.1	654
	260	122.46	11.6	729	10.9	694
0.14	132	62.172	9.5	622	9	596
	170	80.07	10.4	669	9.9	644
	210	98.91	11.5	725	10.6	680
	260	122.46	11.8	739	11.1	705
0.16	132	62.172	9.7	633	9.2	607
	170	80.07	10.8	689	10.2	659
	210	98.91	11.7	735	10.9	694
	260	122.46	12	749	11.3	713

[a] Vc= velocity along chip tool interface, So= feed rate, N= rpm, Temp= temperature

The cutting temperature generally increases with the increase in Vc and So, though in different degree, due to increased energy input and it could be expected that vegetable oil would be more effective at higher values of Vc and So. In the present work, the average chip-tool interface temperature could be effectively measured under dry and wet condition very reliably throughout the experimental domain. However, the distribution of temperature within the tool, work and chip cannot be determined effectively using experimental techniques. The evaluated role of vegetable oil on average chip-tool interface temperature in turning the steel by the uncoated insert at different Vc and So under dry and wet conditions have been shown in fig.7, fig 8, fig 9, fig 10.

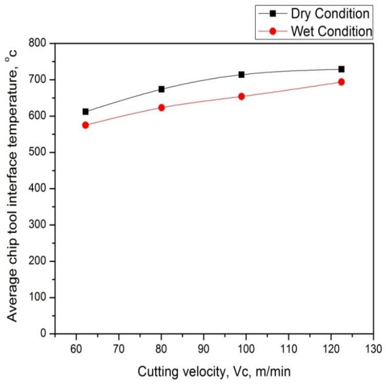


Fig. 8.Variation in θavg.with that of V_c and S_0 in turning steel by SNMG inser under dry and wet condition at 0.12 feed rate.

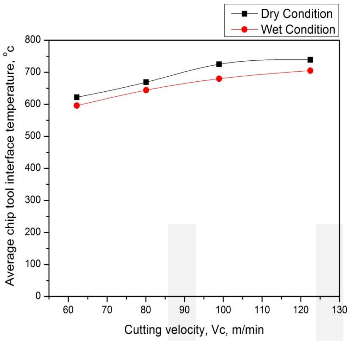


Fig. 9.Variation in θavg.with that of $V_c$and S_0 in turning steel by SNMG inser under dry and wet condition at 0.14 feed rate.

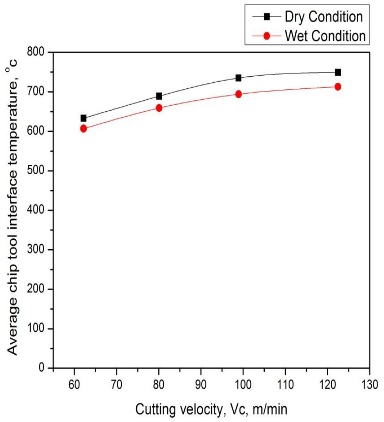


Fig. 10.Variation in θavg.with that of V_c and S_0 in turning steel by SNMG inser under dry and wet condition at 0.16 feed rate.

5 DISCUSSION ON EXPERIMENTAL RESULTS

5.1 Chip-Tool Interface Temperature

The machining temperature at the cutting zone is an important index of machine ability and needs to be controlled as far as possible. Cutting temperature increases with the increase in specific energy consumption and material removal rate [MRR]. During machining any ductile materials, heat is generated at the

1) primary deformation zone due to shear and plastic deformation
2) chip-tool interface due to secondary deformation and sliding and
3) Work-tool interfaces due to rubbing.

All such heat sources produce maximum temperature at the chip-tool interface, which substantially influence the chip formation mode, cutting forces and tool life. That is why; attempts are made to reduce this detrimental cutting temperature.Cutting fluid application may, to some extent, cool the tool and the job in bulk but cannot cool and lubricate expectedly and effectively at the chip-tool interface where the temperature is maximum. This is mainly because the flowing chips make mainly bulk contact with the tool rake surface and may be followed by elastic contact just before leaving the contact with the tool. Bulk contact does not allow the cutting fluid to penetrate in the interface. Elastic contact allows slight penetration of the cutting fluid only over a small region by capillary action. The cutting fluid action becomes more and more ineffective at the interface with the increase in Velocity of cutter, Vc when the chip-tool contact becomes almost fully plastic or bulk.

Therefore, application of vegetable oil at chip tool interface is expected to improve upon the aforesaid machinability characteristics that play vital role on productivity, product quality and overall economy in addition to environment-friendliness in machining particularly when the cutting temperature is very high. The average chip-tool interface temperature, θavg have been determined using the tool work thermocouple technique and plotted against cutting velocity for different feeds and environments undertaken. The fig.7, fig 8, fig 9, fig 10are showing the effect of chip-tool interface temperature, θavg under different cutting velocity, Vc and feed rate, So as compared to dry and wet conditions. However, it is clear from the aforementioned figures that with the increase in Vc and So, average chip-tool interface temperature, θavg increased as usual.

The roles of variation of process parameters on percentage reduction of average interface temperature due to vegetable oil have not been uniform. This may be attributed to variation in the chip forms particularly chip-tool contact length, C_N which for a given tool widely vary with the mechanical properties and behaviour of the work material under the cutting conditions. The value of $C_N$affects not only the cutting forces but also the cutting temperature. In the present thermal modelling also the value of C_N had to be incorporated as the span of heat input at the chip-tool interface.

Vegetable oil was found to decrease with the increase in feed also for more intimate chip-tool contact, but still more effective as compared to dry and wet conditions. With the increase in feed rate, so the chip-tool contact length generally increases but the close curvature of the grooves parallel and close to the cutting edges of the insert has reduced the chip-tool contact length and thus possibly helped in reducing the chip-tool interface temperature further. However, it was observed that the application of vegetable oil enabled reduction of the average cutting temperature by about 5% to 10% depending upon the levels of the process parameters, Vc and So. Even such apparently small reduction in the cutting temperature is expected to have some favourable influence on other machinability indices.

6 CONCLUSION

Based on the results of the present experimental investigation the conclusion can be drawn as like Vegetable oil provided significant improvements expectedly, though in varying degree, in respect of chip formation modes, surface finish throughout the Vc-So range undertaken mainly due to reduction in the average chip tool interface temperature. Flood cooling by soluble oil could not control the cutting temperature appreciably and its effectiveness decreased further with the increase in cutting velocity and feed rate.The present applying systems of vegetable oil enabled reduction in average chip-tool interface temperature up to 10% depending upon the cutting conditions and even such apparently small reduction, unlike common belief, enabled significant improvement in the major machinability indices. Due to vegetable oil application, the form and colour of the steel chips became favourable for more effective cooling and improvement in nature of interaction at the chip-tool interface.The significant contribution of applying vegetable oil in machining the steel by the carbide insert undertaken has been the reduction in flank wear, which would enable either remarkable improvement in tool life or enhancement of productivity (MRR) allowing higher cutting velocity and feed. Such reduction in tool wear might have been possible for retardation of abrasion, decrease or prevention of adhesion and diffusion type thermal sensitivity wear at the flanks and reduction of built-up edge formation which accelerates wear at the cutting edges by chipping and flaking. Vegetable oil reduces deep grooving, which is very detrimental and may cause premature and catastrophic failure of the cutting tools.In machining ductile metals even with cutting fluid, the increase in cutting velocity reduces the ductility of the work material and causes production of long continuous chips.Vegetable oil, if properly employed, can enable significant improvement in both productivity and product quality and hence overall machining economy even after covering the cost of vegetable oil.

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