International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 6089-6101

http://www.ripublication.com

Turning Of AISI 4130 Alloy Steel Using Vegetable Oil Based Cutting Fluid By Minimum Quantity Lubrication

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ABSTRACT

In hard metal cutting operation, the use of cutting fluid has become more problematic in terms of both operator health and environmental aspects. Due to this some alternatives have been tried to minimize or to avoid the use of cutting fluid while machining. Some of the alternatives methods are machining without any cutting fluid and machining with minimum quantity of lubrication (MQL). Taking these into consideration, the project deals with the experimental investigations in the role of MQL on cutting temperature, chip formation and surface roughness in turning AISI-4130 alloy steel at different speed-feed combinations by carbide cutting tool. The results have been compared with dry machining and machining with vegetable oil (palm oil) as coolant. The experimental results show that MQL enables substantial reduction in the cutting temperature, surface roughness depending upon the levels of the cutting velocity and feed and depth of cut. It was also noticed that the chip formation becomes more favorable under MQL condition. Therefore, it is clear that MQL, if properly implemented, not only provides environment friendliness but can also improve the machinability characteristics.

Keywords: MQL, Vegetable oil, Cutting Speed(V_c), Feed Rate(S_O), Surface roughness(R_a), Machinability

1. INTRODUCTION

Metal working fluids are one of the types of lubricants, which are used in machining operations. There are many types of metalworking fluids (MWFs), which may be used to carry out such tasks. Most of the MWFs are mineral oil based fluids. . In general, vegetable oils are highly attractive substitutes for petroleum-based oils because they are environmental friendly, renewable, less toxic and easily biodegradable. Consequently, currently, vegetable based oils are more potential candidates for the use in industry as lubricants/MWFs. Many investigations are in progress to develop new bio based cutting fluids based on various vegetable oils available around the world. Vegetable oils primarily consist of triglycerides, they are glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages. The fatty acids found in natural vegetable oils differ in chain length and number of single and double bonds. The fatty acid composition is determined by the position of carbon-carbon double bonds.

1.1 PALM OIL

Palm oil is a dark yellow to yellow-red oil (high carotene content) of vegetable origin obtained by pressing or boiling the flesh of the fruit of the oil palm (Elaeis guineensis). Palm oil different from palm kernel oil, the latter being taken from the kernels of the oil palm. Palm oil is processed to produce edible fats (margarine), soaps and candles and is used in pharmacy and cosmetics and as an important raw material in oleo chemistry (fat chemistry).The density of palm oil is around 0.921 - 0.947 cm3. Palm oil has a relatively high solidification point/range of 41 - 31°C.

Palm oil is sensitive to contamination by ferrous and rust particles and especially seawater. The barrels must be thoroughly cleaned (rinse out with fresh water) and hygienic before filling. Palm oil has an unpleasant, sweetish (violet-like) odour and a neutral taste.

Cooling lubricants are also responsible for a variety of secondary functions, like the transport of chips, and also cleaning of cutting tools, work and fixtures.

1.2 MINIMUM QUANTITY LUBRICATION

In cutting operations, minimum quantity cooling lubrication (MQCL) is the key to successful dry machining. Flood coolant commonly used in machining operations is going to replace with a minute amount of high-quality lubricant specifically applied at the interface of the tool and work piece**.**

2. EXPERIMENTAL SET UP

Experiments were carried out by plain turning a 36 mm diameter and 500 mm long rod of AISI 4130 alloy steel of common use in a powerful and rigid lathe (Germany, 15hp) at different cutting velocities and feeds under dry condition , wet lubrication and MQL by vegetable oil conditions. These experimental investigations were conducted with a view to explore the role of MQL on the machinability characteristics of that work material mainly in terms of cutting temperature, chip formation and surface roughness.. The ranges of the cutting velocity (Vc) and feed rate (S_o) were selected based on the tool manufacturer’s recommendation and industrial practices. Depth of cut was kept fixed to only 1.0mm, which would serve the present purpose.

Machining ferrous metals by carbides is a major activity in the machining industries. In cutting of steel involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip–tool contact. Again, the temperature at cutting zone increases further with the increase in strength and hardness of the steels for more specific energy requirement. Keeping these things in view, the commonly used alloy steel like AISI 4130 was considered in this experimental work.

1. The MQL needs to be supplied at 100 ml/hr and impinged through the nozzle on the cutting zone. Considering the conditions required for the present work and uninterrupted supply of MQL at a constant rate is used . The schematic view of the MQL set-up is shown in Figure (1) In this system, a small setup was made to supply oil at gravity pressure through a hose pipe.
2. During experimentation, the MQL was projected at the tip of the cutting tool. Consequently, the coolant reached as close to the chip–tool and the work-tool interfaces as possible. The MQL jet was used mainly to target the rake and flank surface and to protect the auxiliary flank to enable better dimensional accuracy.
3. The cutting speed of 250,400,635rpm, and feed rates of 0.10,0.14, 0.18mm/rev are selected by considering the material and tool properties for dry condition, wet lubrication and MQL conditions, with carbide tip as cutting tool and the experiments are conducted. palm oil is used as lubricating oil in wet and MQL condition.

Fig 1 Minimum quantity lubrication setup

2.1 Selection of Machinability Characteristics

The effectiveness, efficiency and overall economy of machining of any work material by given tools depend largely on the machinability characteristics of the tool-work materials under the recommended condition. Machinability is usually judged by

(i) cutting zone temperature, which affects the product quality and cutting tool Performance.

(ii) chip formation mode and pattern .

(iii) Magnitude of the cutting forces, which will affect the requirement of power, dimensional accuracy, vibration and noise.
(iv) Surface finish.

In this work, cutting temperature, shape of the chip, chip formation mode, and surface roughness were considered for studying the role of minimum quantity lubrication.

Table 1 Experimental Readings For MQL Machining

S.NO	SPEED(RPM)	FEED mm/rev	DEPTH OF CUT MM	TEMP IN°C	CHIP COLOUR	SURFACE ROUGHNESS(Ra μm)
1	250	0.10	1	42	WHITE	1.74
2	400	0.10	1	54	WHITE	2.11
3	635	0.10	1	66	BURUT BLUE	1.95
4	250	0.14	1	60	BURNT BLUE	2.12
5	400	0.14	1	71	GOLDEN	2.55
6	635	0.14	1	79	BURNT BLUE	3.11
7	250	0.18	1	64	GOLDEN	3.32
8	400	0.18	1	69	GOLDEN	2.26
9	635	0.18	1	93	BURNT BLUE	1.72

2.2 Temperature And Surface Roughness Measurement

Temperature is measured through digital thermometer. It can measure up to the range of 750ºC by attaching a sensor to it. One end of the sensor is attached to the digital meter and other end is connected to the tool tip, when the tool is cutting the material the average tool chip temperature is taken.Surface roughness tester is used to measure the surface of the work piece.

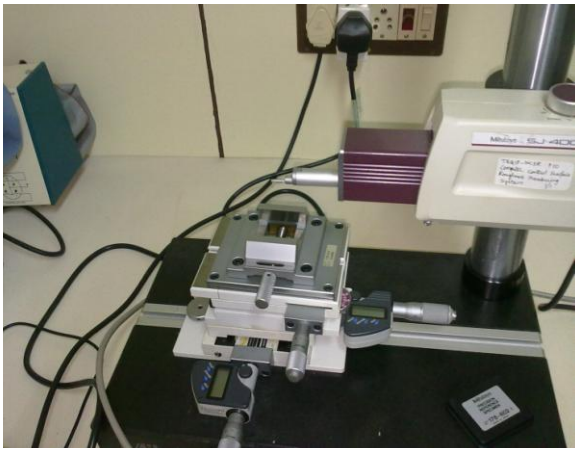


Fig 2 Surface Roughness Tester

Fig 3 Digital Thermometer

2.3 Chip formation

The form (shape and colour) and thickness of the chips directly and indirectly indicate the nature of chip–tool interaction influenced by the machining environment. The pattern of chips in machining ductile metals were found to depend on the mechanical properties of the work material, tool geometry particularly rakes angle, levels of Vc and S0, nature of chip–tool interaction and cutting environment. If chip breaker is not used, length and uniformity of Chips increase with the increase in ductility and softness of the work material, rake angle and velocity unless the chip–tool interaction is adverse causing intensive friction and built-up edge formation.

Fig 4 Different modes of chip formation in MQL

2.4 Wet machining

Wet machining is carried out under continuous supply of palm oil through nozzle under constant pressure, the parameters are varied accordingly and temperature, surface roughness readings are taken after each experiment.. The main drawback of flood machining is more amount of fluid is needed, lot of environmental pollution will occur and also problem to working labour.

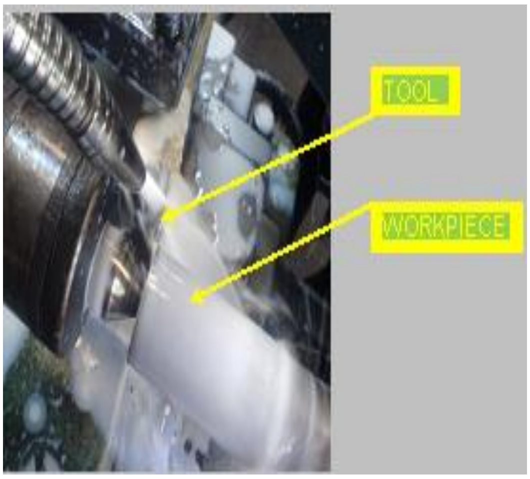


Fig 5 wet machining Process.

Table 2 Experimental Readings For wet Machining

S.NO	SPEED(RPM)	FEED mm/rev	DEPTH OF CUT (MM)	TEMP IN°C	CHIP COLOUR	SURFACE ROUGHNESS(Ra μm)
1	250	0.10	1	44	WHITE	2.01
2	400	0.10	1	48	WHITE	2.73
3	635	0.10	1	65	GOLDEN	2.62
4	250	0.14	1	46	WHITE	2.32
5	400	0.14	1	54	BURNT BLUE	2.84
6	635	0.14	1	63	BURNT BLUE	3.21
7	250	0.18	1	42	GOLDEN	3.60
8	400	0.18	1	51	GOLDEN	2.93
9	635	0.18	1	73	GOLDEN	2.49

Fig 6 Chip Formation Mode In Wet Machining

2.5 Dry Machining

Dry machining is ecologically desirable and it will be considered as a necessity for manufacturing enterprises in future. Industries will be asked to implement consider dry machining to enforce environmental protection laws for occupational safety and health laws. The advantages of dry machining are, non-pollution of the atmosphere (or water), no residue on the swarf which will be reflected in reduced disposal and cleaning costs; no danger to health; and it is non-injurious to skin. Moreover, it reduces the cost of machining. However dry machining operations, the friction and adhesion is more chip tool interface, which lead to higher temperatures, wear rates, leads to shorter tool lives. Dry machining is now of great interest because of environmentally friendly manufacturing. But in practical sometimes less effective when higher cutting efficiency, good surface finish quality and severe cutting conditions are required. Here without using lubricating oil the machining is done under different cutting parameters.

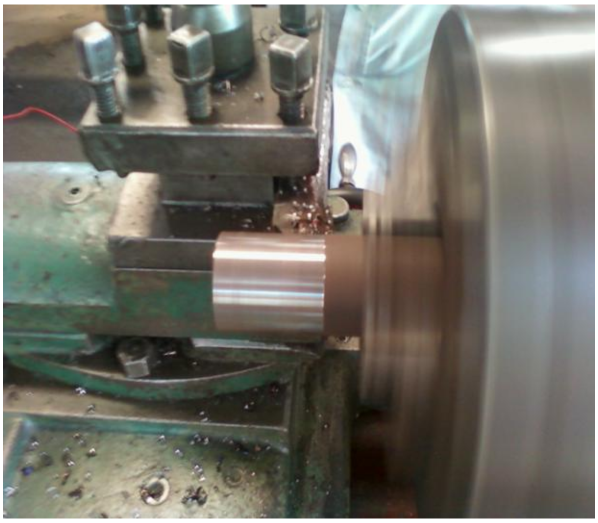


Fig 7 Dry machining

Table 3 Experimental Readings For wet Machining

S.NO	SPEED(RPM)	FEED mm/rev	DEPTH OF CUT MM	TEMP IN°C	CHIP COLOUR	SURFACE ROUGHNESS(Ra μm)
1	250	0.10	1	45	WHITE	1.65
2	400	0.10	1	60	WHITE	2.46
3	635	0.10	1	109	BURNT BLUE	2.02
4	250	0.14	1	86	WHITE	2.54
5	400	0.14	1	89	WHITE	3.15
6	635	0.14	1	105	BURNT BLUE	4.04
7	250	0.18	1	90	WHITE	3.30
8	400	0.18	1	92	BURNT BLUE	2.41
9	635	0.18	1	101	GOLDEN	2.44

Fig 8 Chip Formation Mode In Dry Machining

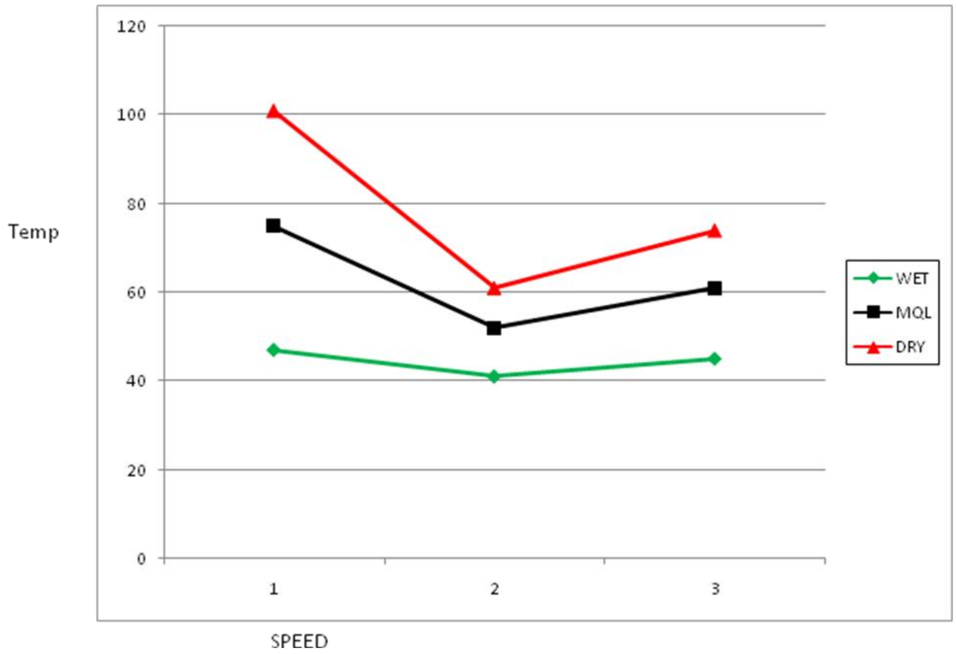
3 RESULTS AND DISCUSSIONS

3.1 Effects On Cutting Temperature

The machining temperature at the cutting zone is an important index of machinability and needs to be controlled as far as possible. During machining any ductile materials, heat is generated at the deformation zone due to plastic deformation, whereas secondary deformation causes heat generation at chip–tool interface. Furthermore, rubbing produces heat at work–tool interfaces.

All such heat sources produce maximum temperature at the chip–tool interface, which effects the chip formation mode, cutting forces and tool life. Attempts are made to reduce the cutting temperature. The cutting fluid action becomes more ineffective at the interface with the increase in Vc when the chip–tool contact becomes almost fully plastic.The application of MQL at chip–tool interface is expected to improve on a aforementioned machinability characteristics that play vital role on productivity. The average chip–tool interface temperature was measured using the digital thermo meter and plotted against experiment number and temperature. Graph(a) . Shows the effect of minimum quantity lubrication on average chip–tool interface temperature under different cutting speeds and as compared dry and wet conditions.

However, it is clear from the aforementioned figure that with the increase in cutting speed and feed, average chip–tool interface temperature increased as usual, even under MQL condition, due to increase in input. The roles of process parameters on percentage reduction of average interface temperature due to MQL have not been uniform. This may result in chip forms variation particularly chip–tool contact length which for a given tool widely vary with the mechanical properties and behavior of the work material under the cutting conditions. This chip–tool contact length affects not only the cutting forces but also the cutting temperature.



a) Speed Vs Temperature

Apparently, more reduction in average chip–tool interface temperature, average is expected by employing MQL but, in practice, reduction in temperature is found to be less because the MQL could not reach the intimate chip–tool contact zone. However, during machining at lower Vc when the chip–tool contact is partially elastic, at chip leaving the tool, MQL is pulled in that elastic contact zone in small quantity by capillary effect and is likely to enable more effective cooling. With the increase in Vc the chip makes fully plastic or bulk contact with the tool rake surface and prevents any fluid from entering into the hot chip–tool interface.

Besides, during minimum application, the cutting fluid is applied at the tool–work interface and there is a possibility of some tiny fluid particles penetrating the work surface near the cutting edge that forms the top of the chip in the next revolution. These particles, owing to their high velocity and smaller physical size can penetrate and firmly adhere to the work surface resulting in the promotion of plastic flow on the backside of the chip due to the effect of rebinding. This relieves a part of the compressive stress and promotes chip curl that reduces tool-chip contact length. This phenomenon, in turns, helps in reducing the chip–tool interface temperature further. The effectiveness of the MQL by vegetable oil was found to decrease with the increase in feed also for more intimate chip–tool contact. Nevertheless, still MQL was found to be effective as compared to dry condition and almost having same temperature to wet cooling conditions. It was observed that the MQL in its present way of application enabled reduction of temperature almost in the range of wet conditioning.

3.2 Effects of MQL on chip formation

The form (shape and colour) and thickness of the chips directly and indirectly indicate the nature of chip–tool interaction influenced by the machining environment. The pattern of chips in machining ductile metals were found to depend on the mechanical properties of the work material, tool geometry particularly rakes angle, levels of Vc and S_o, nature of chip–tool interaction and cutting environment.

If the chip breaker is not present, length and uniformity of chips increase with the increase in ductility and softness of the work material, rake angle and velocity unless the chip–tool interaction is adverse causing intensive friction and built-up edge formation. AISI 4130 steel when machined by the pattern type uncoated carbide insert under both dry and we conditions produced ribbon type continuous chips at lower feed rates and more or less tubular type continuous chips at high feed rates. When machined with MQL the form of ductile chips did not change appreciably but their back surface appeared much brighter and smooth. This shows that the amount of reduction of temperature and presence of MQL application enabled favourable chip–tool interaction and elimination of even trace of built-up edge formation.

The colour of the chips became much lighter i.e. blue or golden from burnt blue depending on Vc and S_o due to reduction in cutting temperature by minimum quantity lubrication.

Chip reduction coefficient is also an important machinability index. For given cutting conditions, the value of depends on the nature of chip tool interaction, contact length of chip and chip form all of which are expected to be influenced by MQL in addition to the levels of Vc and S_o. The variation in value of with Vc and S_o as well as machining environment are shown in. Almost all the parameters involved in machining have direct and indirect influence on the thickness of the chips during deformation. The degree of chip thickening is assessed by chip reduction coefficient that plays significant role on cutting forces and hence on cutting energy requirements and cutting temperature. The aforementioned figures clearly show that throughout the present experimental domain the value of gradually decreased with the increase of Vc though in different degree under dry, wet and MQL by vegetable oil conditions. The value of usually decreases with the increase in Vc particularly at its lower range due to plasticization and shrinkage of the shear zone for reduction in friction and built-up edge formation at the chip–tool interface due to temperature increase and sliding velocity. In machining steel by carbide tool, usually, usually, the possibility of built-up edge formation, and size and strength of the edge if gradually increases with the increase in temperature.

3.3 EFFECTS ON SURFACE ROUGHNESS

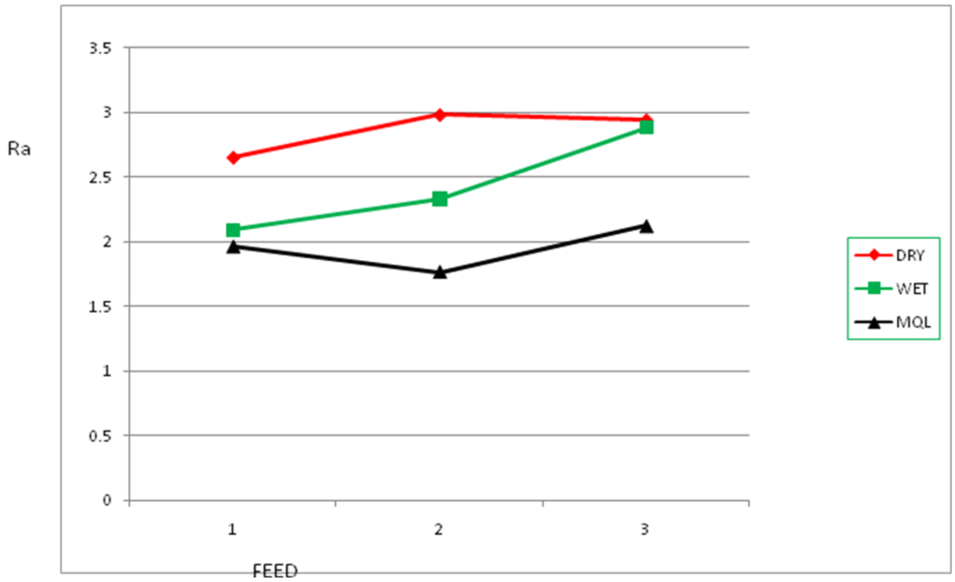
Surface finish is an another important index of machinability as the performance and service life of the machined component are often affected by its good surface finish, nature and extent of stresses and presence of subsurface micro-cracks, particularly that component is to be used under dynamic loading or in conjugation with some other mating parts. The main cause behind development of surface roughness in continuous machining processes like turning ductile metals in particular are

(i) regular feed spots left by the tool-tip on the finished work piece..
(ii) irregular deformation of the auxiliary cutting edge at the tool-tip due to wear, fracturing and chipping.

(iii) vibration in the machining system, and
(iv) built-up edge formation.

The variation in surface roughness observed during turning AISI 4130 low alloy steel by carbide insert at a particular set of cutting velocity, feed rate and depth of cut under dry condition, wet condition and MQL conditions is having better surface roughness.

However, the surface roughness deteriorated drastically under wet machining compared to dry, which might possible be attributed to electrochemical interaction between insert and work piece. It is observed from that surface roughness grows quite fast under dry machining due to temperature, which is more intensive and stresses at the tool-tips. MQL appeared very effective in reducing surface roughness. It is shown that MQL improves surface finish depending on the work-tool materials and mainly through controlling the deterioration of cutting edge abrasion, chipping and built-up edge formation.



b) Feed Vs Surface Roughness

From the above graphs it is clear that Minimum quantity lubrication condition has better surface finish when compare with dry and wet condition. And it is also noted that temperature in MQL condition is nearer to wet condition from the Graph (b).

4. CONCLUSION

Based on the results of the experimental investigation:

i.) Surface finish is improved very much in minimum quantity lubrication compared with dry and wet machining.

ii). MQL provided significant improvements, with respect of chip formation modes and surface finish throughout the range of Vc and S_0 undertaken mainly due to reduction in the average chip–tool interface temperature. From the experimental results wet 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.

iii.) The present MQL systems enabled reduction in average chip–tool interface temperature and is near to wet machining depending upon the cutting conditions and even such apparently small reduction that significant improvement in the major machinability indices.

iv.) The chips produced under both dry and wet condition are of ribbon type continuous chips at lower feed rates and more or less tubular type continuous chips at high feed rates. When machined with MQL the form of the chips did not change appreciably but their back surface appeared much brighter and smoother. This shows that the amount of reduced in temperature and presence of MQL application enabled favourable chip–tool interaction and elimination of even trace of built-up edge formation.

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