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An Experimental Investigation of Effect of Cutting Fluids on Chip Formation and Cycle Time in Turning of EN-24 and EN-31 Material

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Abstract

In metal cutting industries it is essential to study the chip morphology during machining process. The chip formation is not only depending upon the work piece material but even on the cutting fluids and grain structure of the materials. Cutting fluids have seen extensive use and have commonly been viewed as a required addition to high productivity and high quality machining operations. This experiment is to determining the effect of cutting fluids and cutting parameters on chip formation mode and cycle time in turning of EN-24 and EN-31 material. The above operation has been carried out in dry cutting condition, Flood application of cutting fluids. Cutting fluids like soluble oil and palm oil used in the present work. The cutting operations were carried out on a conventional lathe machine there by making turning operation with uncoated carbide cutting tool at different spindle speed(n) of 210rpm, 450rpm and 750rpm.Also feed(f) of 0.1rev/min to 0.2rev/min. Depth of cut is kept constant at 1.5mm. By using the vegetable oil we can improve the surface finish, metal removal rate and to reduce the environmental effects. After conducting these experiments it was recorded chip morphology and cycle time value for each fluid under different cutting conditions. It was observed light color chips with segmented form in vegetable based oil at lower cutting conditions for each material.

Keywords: Work piece material, Cutting fluids, Chip formation, Cycle time..

Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality in terms of work piece, chip formation, surface finish, high production rate, less wear on the cutting tools, economy in machining based on cutting fluids and type of work material. It is necessary to determine optimal cutting ranges like speed, feed rate and depth of cut also tool geometry and type of the cutting fluids.

Selection of the cutting parameters [1] and cutting fluids are directly influence on chip morphology and tool chip interface. Cutting fluid is a type of a coolant and lubricant designed especially for metal working and machining processes. Most of the metal working and machining processes can benefit from the use of cutting fluids.

Cutting fluids are employed in machining to reduce friction are employed in machining to reduce friction, cool the workpiece and wash away the chips. With the application of cutting fluid, the tool wear reduces and machined surface quality improves often the cutting fluids also protect the machined surface from corrosion. They also minimize the cutting forces thus saving the energy [2]. The method to be employed for the application of cutting fluids depends upon the type of machining, cutting conditions, tool materials, workpiece materials, accuracy requirements etc [3].

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Therefore, [4] conclusions about reducing cutting tools cost and increased production being achieved through the use of appropriate cutting fluids are highly justified. The cutting fluid should meet the specific requirements of the turning process. In addition to the cooling effects, cutting fluids can lubricate the workpiece, acting decisively to maintain the good quality of the final piece. This fact makes cutting fluids one of the most important parameters in a turning operation process. With regards to the characteristics of cutting fluids, pure oils is believed to have a high lubricating capacity while emulsion has a high cooling capacity.

Shaw et al. [5] experimentally observed that the cutting fluid does not lubricate at high speeds. The possible explanations for this behavior included: chips are carrying cutting fluid away too quickly for it to reach the cutting zone and serve as a fluid-film lubricant and the time is too short for the fluid to chemically react with metal surfaces to form a solid-film lubricant. Cassin and Boothroyd [6] also found that no lubrication was evident at high cutting speeds. They suggested that lubrication occurs at low speeds by diffusion through the work piece or that the extreme pressure additives within the fluid react to form a boundary layer of solid-film lubricant.

Recently there has been a change in this situation, in part driven by the fact that costs associated with fluid use often constitute between 7% and 17% of total production costs, as compared to 4% for tooling costs [7]. Fluid related expenses include the cost of installing a fluid supply system, fluid purchase and system maintenance, and discarded fluid (waste) treatment. Fluid-related costs are large because high production manufacturing plants frequently utilize several cutting fluid reservoirs each containing thousands of gallons of cutting fluid, and often an entire reservoir is flushed to clean the system when quality issues arise [8]-certainly, reducing the amount of fluid employed can produce significant cost and waste savings.

Lahres et al. [9] presented dry machining of synchronizing cones for automotive application. The work material was austenitic 22Mn6 steel. In the first step of their study, dry machining was compared to machining with coolant and with minimal lubricant system. The used minimal lubricant system worked with special oil, which had food-grade quality. The oil volume flow was about 50 ml/min and the air volume oil was About 20 ml/h; hence, the produced chips were dry after leaving the contact zone of the cutting process. At this oil volume flow, a single chip can carry a maximum of 1 µl. Therefore, the chips could be declared as being almost dry and passed for metallic recycling without further treatment. The results exhibited an advantage for the minimal lubricant technique and for the dry machining.

EN-24 Material**:** EN-24 is medium alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear. The EN24 alloy steel is required to be heated to a temperature of 900 ^{0}C to 950 ^{0}C for hardening and followed by quenching in a oil medium. It is then tempered with temperature of 200 ^{0}C to 225 ^{0}C and obtains a final hardness of 45 to 55 HRC [10]. EN-31 Material- EN-31 is a type of chrome alloy steel. It contains a combination of Carbon, Manganese, Silicon, Phosphorus, Sulphur, Nickel and Chromium.

EN 24 is 5% nickel chromium, molybdenum high tensile grade usually supplied hardened and tempered to W condition. EN 24 has a tensile strength of 1075/1225 N/mm^2. EN24 is a commonly used engineering steel for application that require a higher tensile than EN24T.Typical application includes gears, shafts, studs, bolts and heavy duty axels. Properties of the EN 24 steel like Low specific heat, and tendency to strain harden and diffuse between tool and work material, give rise to certain problems in machining such as large cutting force, high cutting temperature, poor surface finish and built up edge formation. This material is thus difficult to machine [11]. EN-31 is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. During the cutting operation, several types of vibrations influence the chip flow-rate and final work surface [12].

Chip formation

The portion of the material that has been cut away from the work material by the cutting tool is called chip. Chip formation is a complex phenomenon, when a force is applied to the cutting tool. The material of the workpiece ahead of the cutting edge deforms owing to the shearing action. Formation of the chip and its motion along the tool face can be visualized from an idealized model in which a stack of inclined playing cards is pushed against the tool.

Generally in machining process chip formation is very important to the manufacturer. The shape and size of the chip obtained from a machining process indicated the type and quality of the process,

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irrespective of the machining process, the following four basic types of chips are produced.

1. Segmental or discontinuous chip.
2. Continuous chip.
3. Continuous chip with built up edge.
4. Non homogeneous chip.

According to some authors [1,13] Preliminary studies have shown that for American Iron and Steel Institute (AISI) 4340 steel, the valid range of feed rates corresponds to shear-localized chip formation. Shear-localized chips are also called saw-tooth chips are serrated chips. They have been observed for materials such as AISI 4340 steel [13], Titanium and its alloys and nickel iron based super alloys. Shaw [14] identified serrated or shear-localized chips and characterized them as oscillatory material flow. Other researchers have observed that the chip propagates from the free surface towards the tool tip.

From the research point of view the main objective of the present work is to experimentally investigate the role of vegetable oil-based cutting fluid on chip color chip shape and cycle time in turning EN 24 and EN 31 steel by the industrially used uncoated carbide tool (SNMG 120408) at different spindle speeds and feeds combinations as compared to wet and dry machining.

Experimentation

Work material

In the present experiment EN 24 steel and EN 31steel of diameter ø50mm and length 150mm used as a work material shown in Figure 1a and 1b. Generally these materials are commonly used grade in automobile industries and machine tool industries. Chemical composition of the two different materials is shown in Table 1 and 2.

Table 1. Chemical composition of EN-24 steel

Chemical composition	Min%	Max%
Carbon	0.36	0.44
Silicon	0.10	0.35
Manganese	0.45	0.70
Nickel	1.30	1.70
Chromium	1.00	1.40
Molybdenum	0.20	0.35
Phosphorous	0	0.035
Sulphur	0	0.04

Table 2. Chemical composition of EN-31 steel

Chemical composition	Min%	Max%
Carbon	0.90	1.20
Silicon	0.10	3.5
Manganese	0.30	0.75
Nickel	0	0
Chromium	1.00	1.60
Molybdenum	0	0
Phosphorous	0	0.040
Sulphur	0	0.040

(a)

(b)

Fig. 1 a) En-24 material b) En-31 material

Cutting fluids

Cutting fluids affect tool-life to a great extent. A Cutting fluid does not only carry away the heat generated and keep the tool, chip and work piece cool, but reduces the coefficient of friction at the chip-tool interface and increases tool-life. Cutting fluids are used throughout the industry in many metal cutting operations and they are classified into three categories: Neat cutting oils, water soluble oil and gases. Here two types of cutting fluids are used in the present experiment shown in figure they are,

Vegetable oil- Palm oil being a vegetable oil is cholesterol free having a naturally semi solid characteristic at room temperature with a specific origin melting point between 33 ^{0}C to 39 ^{0}C. It does

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not require hydrogenation for use as a food an ingredient.

a *b*

Fig. 2 (a) Palm oil b) Soluble oil

CPO is deep orange red in color due to the high content of natural carotenes palm oil is rich source of carotenoids and vitamin E which confers natural stability against oxidative deterioration. Palm oil has a balanced ratio of unsaturated and saturated fatty acids.

It contains 40% oleic acid (mano unsaturated fatty acid). 10% iinoleic (poly unsaturated fatty acid) 45% palmitic acid and 5% stearic acid (saturated fatty acid). This composition results in an edible oil that is suitable for use in variety of food application. This composition results in an edible oil that is suitable for use in variety of food application.

Soluble oil- In chemical company manufactures a complete and highly versatile line of water-soluble oil coolants engineered for use in machining operation. They are formulated with premium base oils. Unique emulsion packages highly effective bio-resistant components and select extreme pressure additives to provide maxi tool life and promote fine finishes. ICC'S soluble oils from clean, robust and stable emulsions when mixed with hard and soft water.

Machining

The experiments were performed on a conventional turning (Lathe) machine shown in Figure.3.Machining length is 100mm and diameter of 50mm. All tests were carried out in dry and wet conditions using soluble oil and vegetable based oil (Palm oil). Uncoated carbide tool used for machining process and three different cutting speeds and Feed rates (f) were employed throughout the experiments. Depth of cut (doc) was kept constant at 1.5 mm. Experimental tests were performed under different cutting conditions shown in Table 2 and cycle time were recorded and chips were collected for every two cuts (passes) with each cutting conditions and environment. The effects of spindle speed (n), feed rate (f), on Cycle time and chip formation were studied for different fluids.

Fig. 3 Conventional lathe machining process

Result and discussion

The experiments were conducted to study the output response characteristics with the process parameters and lubrications. In this section presents the experimental results of cycle time, chip morphology (shape and color) are shown in Table 3 & 4 for EN 24 material, Table 5 and 6 for EN 31 material respectively. Based on some research papers various authors have demonstrated the chip formation with varying cutting conditions. Since only few studies was observed with different cutting environment and varying speeds(n).In this experiments we conceder two different EN Steels with three different cutting environments(lubrication) as given in the following tables, were carried out at three different speeds (n).

Table 3. Experimental details for EN-24 steel

Sl. No	Speed (rpm)	Feed rate (mm/rev)	Cycle time (sec)	Environment
1	280	0.10	206	DRY
2	450	0.11	127	
3	710	0.2	85	
4	280	0.10	206	SOLUBLE OIL
5	450	0.11	127	
6	710	0.2	85	
7	280	0.10	206	

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8	450	0.11	127	PALM OIL
9	710	0.2	85	

Table 4. Experimental details for EN-31 steel

Sl. No.	Speed (rpm)	Feed (mm/rev)	Cycle time (sec)	Environment
1	280	0.10	206	DRY
2	450	0.11	120	
3	710	0.2	82	
4	280	0.10	206	SOLUBLE OIL
5	450	0.11	120	
6	710	0.2	82	
7	280	0.10	206	PALM OIL
8	450	0.11	120	
9	710	0.2	82	

Table 5. Shape and color of chips for EN-24 at different speed and fluids

Sl. no	Speed (rpm)	Shape of chip	Color of chip	Environment
1	280	Tubular	Blue	DRY
2	450	Helical	Golden	
3	710	Continuous tubular	Burnt bluish	
4	280	Segmented (Discontinuous)	Golden burnish	SOLUBLE OIL
5	450	Tubular	Golden	
6	710	Continuous or ribbon	Blue	
7	280	Helical	Blue	PALM OIL
8	450	Helical	Golden mix blue	
9	710	Tubular	Burnish blue	

Table 6. Shape and color of chips for EN-31 at different speeds and fluids

Sl. No.	Speed in (rpm)	Shape of chip	Color of chip	Environment
1	280	Helical	Golden	DRY
2	450	Continuous Helical	Golden burnish	
3	710	Continuous or ribbon	Light blue	
4	280	Helical	Golden	SOLUBLE OIL
5	450	Continuous Helical	Golden brownish	
6	710	Continuous or ribbon	Dark bluish	
7	280	Helical	Golden	PALM OIL
8	450	Tubular	Golden Burnish	
9	710	Continuous or ribbon	Burnish	

From the above experimental conditions different types of chips are obtained are as given in the following sections.

Effect of cutting fluids on chip formation for En-24 and EN-31 material

a) Tubular

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b) Helical

(c) Segmented or Half turn

d) Tubular shape

(e) Ribbon shape

(f) Helical

(g) Continuous Tubular

(h) Continuous Helical

Fig 4. Different types of chips formation at various spindle speeds and cutting environment.

The chip samples were collected after machining with different spindle speeds (n) under dry, wet and vegetable oil conditions. The form and color of all those chips were watchfully examined and noted down. The thicknesses of the chips were repeatedly measured. According to experimental results it was evident that chip morphology like the form (shape, color) and thickness of the chips directly and indirectly indicate the nature of chip–tool interaction influenced by the machining environment. While machining the pattern of chips in machining ductile metals were found to depend on the mechanical properties of the work material, cutting conditions (levels) tool geometry particularly rakes angle and cutting environment (Lubrication). In absence of chip

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breaker, length and uniformity of chips increase with the increase in ductility and softness of the work material, tool rake angle and cutting velocity unless the chip–tool interaction is adverse causing intensive friction and built-up edge formation.

Table 5 shows that while machining of EN 24 and EN 31 materials in dry condition produced tubular with helical shape type chips at lower speed rates of 280rpm and 450rpm more or less tubular type with continuous chips and ribbon shape chips at higher speed rate710rpm given in figure 4 a and e. It can be explain that chip tool interface temperature increase with increasing the speed, feed rates and also due to the friction and adhesion between chip tool tend to be higher temperature in dry machining increases ductility of the work piece due to high temperature as well as tool without chip breaker, it is difficult break the chips at tool and wok interface area which produce the chips in to tubular form at lower speeds and continuous tubular and ribbon form at higher speeds. Where as in case of soluble oil while machining, it was observed segmented (dis continuous) chips with golden color at lower speed, due to lower speed it required larger stress to remove the material from the material with more area of contact with tool and work surface and high temperature in cutting zone has controlled due to soluble oil which results, chips will break from the tool and work interface area which produces segmented (dis continuous) chips shown in figure 4a.

At higher speed like 710rpm with three different cutting environments, while machining both EN-24 and EN-31 materials it was observed that shape of the chip is continuous ribbon shape chips with burnish and burnish blue color given in Table 5 and 6. It can be explained as, while machining [15] heat is generated at the primary deformation zone due to shear and plastic deformation, whereas secondary deformation and sliding cause 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 substantially influence the chip formation mode. Due to secondary deformation and chip tool interfaces temperature due to sliding causes rubbing and, it leads to increases the maximum friction between contact surfaces (tool and work surface, which results increase in the temperature of the chips which produces dark bluish color and burnish color chips which indicate the increase in temperature at contact surfaces. The heat generation becomes more intensified in machining of hard materials it requires more energy than cutting a low strength material it results cutting temperatures in the tool and the work-piece rise significantly during machining of all materials [18].

When machining process carried out using palm oil as lubrication, the form of the chips is helical and tubular shape with golden color and golden burnish color. The color of the chips became much lighter i.e. blue or golden form burnt blue depending on spindle speed(n) and feed due to application flood fluid(vegetable oil as lubrication) reduction in co efficient of friction at the interface of the tool and chip (cutting temperature). Also it was observed back surface appeared much brighter and smoother. This indicates that the amount of reduction of temperature and less chemical reaction of fluid with tool and work surface due to environmentally friendly. In addition fluids can help to disposal of the chips and control the chip formation (shape and color), which decrease the contact length between chip and tool which helps to break the chips [19]. It was also recorded by some research persons [6] they found that no lubrication was evident at high cutting speeds. They suggested that lubrication occurs at low speeds by diffusion through the work piece or that the extreme pressure additives within the fluid react to form a boundary layer of solid-film lubricant. Shaw et al. [5] experimentally observed that the cutting fluid does not lubricate at high speeds. The possible explanations for this behavior included: chips are carrying cutting fluid away too quickly for it to reach the cutting zone and serve as a fluid-film lubricant and the time is too short for the fluid to chemically react with metal surfaces to form a solid-film lubricant.

On other hand while machining with varying in value of speed and feed rate as well as machining environments for both materials, chip thickness is minimum which are shown in Figure 4 b and d, that almost all the parameters involved in machining have direct and indirect influence on the thickness of the chips during deformation, specially at minimum speed (n) value like 280rpm to 450rpm thickness of the chips is less with light (Bright) color with smooth surface. The degree of chip thickening is less at lower speed value due to larger stress required to remove the material from the work surface causes the variation in chip thickness value and break the chips continuously at certain length. Also chip thickness assessed by chip reduction coefficient that plays significant role on cutting forces and hence on cutting energy requirements and cutting temperature [15].

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According to Table 3 and 4, it was noticed that the effect of spindle speed (n) and feed rate on cycle time while machining EN24 and EN31 steels using three different cutting environments. It can be observed clearly from the tables 3 and 4 that, as the speed increases cycle time (processing time) decreases. At speed (n) 280rpm to 450rpm time taken to complete the overall processing is 207sec and 127sec. At 450rpm over all processing time (cycle time) is decreased that twice time of the initial speed value (280rpm) shown in tables. Whereas at 710rpm least processing time was obtained that is 85sec. This is due to the less area of contact between tool and work piece with higher speed and feed value. It was evident by results, where the speed (n) and feed increased, processing speed become high, there by reduces the processing time or cycle time [16]. It was observed that at lower spindle speed and feed rate it requires larger forces and stress to deform the material in the cutting zone as a results material removal rate is decreases [17]. At higher feed rate tool travels rapidly and resulting less cycle time as well as sufficient cooling at tool and chip interface reduce the heat and easily remove the chips at cutting area which results to increase material removal rate with less time. Also due to less area of contact between tool and work piece. In addition cutting fluids helps to breaking up chops from the cutting area more efficiently, which means the cutting tool spent less time for breaking metal chips[20]. According to results given in tables it was evident that cutting conditions and fluids types both are significant factor on cycle time and chip morphology (shape and color of the chips).

Conclusions

Based on the results of the present experimental investigation,
the following conclusions can be drawn:

- Vegetable based oil provided significant improvements expectedly, though in varying degree, in respect of chip formation modes, cycle time throughout the range of spindle speed and feed rate undertaken mainly due to reduction in the average chip–tool interface temperature.
- The chips produced under both dry and wet condition are of ribbon type continuous chips at higher speed (n) rates of 710rpm with burnish blue color.
- At lower speed (n) 210rpm to 450rpm and feed value form of the chips is less tubular and continuous helical shaped chips for both EN 24 and EN 31 steel.
- In wet condition Chip thickness is decreased at 210rpm to 450rpm range with bright color (Golden color and light blue color) with smooth surface due to reduction in temperature for both materials.
- Performance of the vegetable based oil is superior compare to soluble oil in terms of shape and color of chips.
- Cutting environment (fluids) and cutting conditions are the significant factor effect on chip formation (shape, color) and thickness of the chips.
- Cycle time decreased at higher speed (n) value with all three cutting environments for each material.
- The type of the steel grade does not effect on the chip formation, according to experimental results.

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