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Cutting Fluid – A Review

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Abstract: **Cutting Fluids are widely used in manufacturing industries as it is helpful to cool the tool and workpiece, to lubricate the chip-tool interface and to increase tool life. In this article different machining environments and different types of cutting fluids are reviewed. An attempt is made to summarize some important published research work on the effect of different machining environment on workpiece temperature and its hardness after machining, thrust force, average surface roughness and flank wear. Minimum quantity lubrication using Nano fluids is the recent technology to reduce the negative environmental impact of cutting fluid with increased thermal and tribological properties.**

Keywords: **Cutting fluid, Machining, MQL.**

I. INTRODUCTION

The use of cutting fluids in metal machining was first reported in 1894 by F. Taylor who noticed that cutting speed could be increased up to 33% without reducing tool life by applying large amounts of water in the cutting zone [1]. The selection of suitable cutting fluids is one of the most important and cheapest factors in enhancing the performance of cutting tools. In metal machining process, the condition of the cutting tools plays a significant role in achieving consistent quality and also for controlling the overall cost of manufacturing. To get higher rates of metal removal and at the same time maintain maximum tool life, it is necessary to lubricate as well as cool the chip tool interface. Cutting fluids are designed to fulfil one or more of the following functions;

- To cool the tool and work piece,
- To lubricate the chips tool interface and reduce tool wear due to friction and abrasion,
- To improve the finishing of the machined surface,
- To flush away the chips from the cutting zone,
- To reduce power consumption, wear on the tool, and the generation of heat, by affecting the cutting process. This investigation wishes to establish a relationship between the surface chemistry of the lubricants involved and how they can accomplish reducing the contact length on the rake face of the tool where most of the heat during cutting is produced.
- To prevent the corrosion of the work and machine, to prevent chip welding (formation of a built up edge) [2].

The desirable properties of cutting fluids in general are (Boston, 1952)

- High thermal conductivity for cooling.
- Good lubricating qualities.
- High flash point, should not entail a fire hazard.
- Must not produce a gummy or solid precipitate at ordinary working temperatures.
- Be stable against oxidation.
- Must not promote corrosion or discoloration of the work material.
- Must afford some corrosion protection to newly formed surfaces.
- The components of the lubricant must not become rancid easily
- No unpleasant odour must develop from continued use.
- Must not cause skin irritation or contamination.
- A viscosity that will permit free flow from the work and dripping from the chips.

El Baradie [7] put the machining processes in order according to the amount of usable cutting fluids quantity from the smallest amount to the highest amount:

1. Grinding
2. Cutting with saw
3. Turning
4. Planning and shaping
5. Milling
6. Drilling
7. Reaming
8. Threading (using high cutting speed and low feed rate)

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9. Threading operation with shape tools
10. Boring
11. Drilling deep holes
12. Gear production
13. Screwing with thread
14. Screwing with tap
15. Outer broaching
16. Inner broaching.

This arrangement from using less cutting fluids to high would be a general approach and this would not provide detailed view of the type of machining processes. The machined workpiece material, the cutting tool material and cutting tool geometry parameters could change this arrangement [7].

The machining processes have an important place in the traditional production industry. Da Silva et al [3] investigated the cost effectiveness of all machining processes. This is mainly affected by selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and workpiece material. The selection of optimum machining parameters will result in longer tool life, better surface finish and higher material removal rate. During machining process, friction between workpiece-cutting tool and cutting tool-chip interfaces cause high temperature on cutting tool. The effect of this generated heat decreases tool life, increases surface roughness and decreases the dimensional accuracy of work material. This case is more important when machining of difficult-to-cut materials [3]. Various methods have been reported to protect cutting tool from the generated heat. Choosing coated cutting tools are an expensive alternative and generally it is a suitable approach for machining difficult-to-cut materials such as titanium alloys, heat resistance alloys etc. The application of cutting fluids is another alternative to obtain higher material removal rates. Cutting fluids have been used widespread in all machining processes. However, because of their damaging influences on the environment, their applications have been limited in machining processes [4-8], lead to development of newer techniques for applying cutting fluids like MQL.

II.MACHINING ENVIRONMENT

According to Cutting Fluids application machining environment is mainly classified in four types as listed below:

- Dry Machining
- Cryogenic
- Wet environment.
- Minimum Quantity Lubrication (MQL)

(a) Dry Machining: In dry machining cutting fluids are not used therefore friction and cutting temperature will be more than that of wet machining. It can reduce the tool life, surface quality. It can also affect thermally induced geometrical deviations in the machined part. Hence for obtaining long tool lives, it is not recommended to use the dry machining for high values of depth of cut [9,10].

(b) Cryogenic Machining: The use of compressed and chilled gas for cooling in machining operations is termed as cryogenic machining. In cryogenic machining, operations are conducted at very low temperatures below than about 120K. In cryogenic machining the cutting zone temperature, tool and workpiece temperature is reduced by directing liquefied gases (a super cold medium) into cutting zone. Carbon dioxide, Nitrogen, Oxygen, Argon etc. gases are used in cryogenic machining [9]. Cryogenic machining can be considered as cleanest procedure of cooling in metal cutting operations but it provides less lubrication effect and also requires expensive set up for machining.

(c) Wet environment: Wet environment or flood cooling condition is most commonly used method in which a large amount of cutting fluids are continuously applied on cutting tool and work piece interface. In wet environment neat cutting oil or water soluble cutting fluid is used for lubrication of the contact areas between rake face, chips, flank face and machined surface. In wet environment cutting fluids also remove heat induced by friction in cutting zone. These functions of cutting fluids result in improved machinability. The parameters of cutting fluid such as pH value, concentration and bacterial growth etc. plays a very important role in selection of proper cutting fluid. The way of use of cutting fluid with optimum pressure and flow rate is equally very important in the view of performance of machining operation such as tool life, power consumption, cutting forces, surface integrity and machining accuracy. Kamruzzaman et al [11] and Naves et al [12] indicated that application of pressurized cutting fluids shows better performance of machining operations. It helps in increasing tool life, chip breakability and decreases temperatures in the cutting zone and lowers forces. Machinability can be increased by using optimum value of cutting fluid pressure and flow rate, so it is necessary to find out the optimum values of these parameters and also keep attention that the values of these parameters could not be vary throughout the machining process [11,12].

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(d) Minimum Quantity Lubrication (MQL): Lubrication, cooling, and chip flushing functions of cutting fluids makes the performance of machining operations better but its uses also create negative effects on employee health and environment [13]. MQL or near dry lubrication means that the use of cutting fluids with a flow rate of 50 - 500ml/h for only a minute amount [9, 13-15]. MQL has limited effectiveness in machining operation because of it is more effective in lubrication than cooling [16].

To increase the effectiveness of MQL, metallic and nonmetallic nanoparticles are blended in conventional cutting fluids. A colloidal mixture of these nanometer sized (<100 nm) particles in conventional cutting fluid is called nanofluids. Nanofluids are considered to be potential heat transfer fluids because of their superior thermal and tribological properties [27].

Classification of cutting fluid :

Cutting fluids are normally classified in to three main groups. These are

- Gases
- Neat cutting oils or Straight cutting oil
- Water soluble cutting fluids
- Paste or solid lubricants

(a) Gases: Gas based cutting fluids can be used in the form of gas or in the form of cooled pressure fluid. But these are the substances that generally found in the gaseous form at room temperature. Nitrogen, Argon, Helium and Carbon-dioxide are the examples of the gaseous cutting fluids. Liquid coolants cannot be used in some machining operations because in such cases there is a risk of corrosion occurrence over workpiece or machine component so gaseous cutting fluids are beneficial in such cases. Gaseous cutting fluids cannot be reused so that it makes the use of gaseous cutting fluid costly & limited.

(b) Neat cutting oil or straight cutting oil: Neat oils or Straight oils generally refer to petroleum or mineral oils. The petroleum or mineral oils are basically used directly without dilution with water but sometimes to improve specific properties that they have, some specific additives are blended. Generally for light duty machining of ferrous and nonferrous metals additives are not required. For more severe applications extreme pressure (EP) additives such as sulphar, chlorine, or phosphorus compounds may be used with the straight oils. These additives enhance the oil's wettability, lubrication property and improve the oil's ability to handle large amounts of metal fines. The high cost, fire risks, inefficient in high cutting speed, low cooling ability, smoke formation and high risk to the human health etc. factors make the use of straight oils limited.

There are two main types of straight cutting oils;

i. Inactive Straight cutting oils
ii. Active Straight Cutting Oils

i. Inactive Straight cutting oils: Inactive oils contain sulphur that is very firmly attached to the oil. Mineral oils are an example of straight oils. Mineral oils provide excellent lubrication, but are not very good at heat dissipation (removing heat from the cutting tool and work piece). Mineral oils are particularly suited to non-ferrous materials such as aluminium, brass, and magnesium. Blends of mineral oils are also used in grinding operations to produce high surface finishes on ferrous and non- ferrous materials.

ii. Active Straight Cutting Oils: Active oils contain sulphur that is not firmly attached to the oil, i.e. it is part of the oil molecule but is only weakly bonded to the hydro-carbon backbone. Thus the sulphur is easily released during the machining operation to react with the work piece. These oils have good lubrication and cooling properties. Special blends with higher sulphur content are available for heavy duty machining operations. They are recommended for tough low carbon and chrome-alloy steels. They are widely used in thread cutting. They are also good for grinding as they help prevent the grinding wheel from loading up. This increases the life of the grinding wheel.

(c) Water soluble cutting fluids: The primary function of cutting fluid is removal of heat from cutting zone by conduction process, so it is essential for cooling that the used cutting fluid should have high thermal conductivity and specific heat. Specifically, water is the most favourable coolant with low cost accompanied with high thermal conductivity and specific heat. However water has lower lubricating effect and also has corrosive nature to ferrous materials which are most commonly used in machining equipments. To overcome these problems different additives have been added to water [17]. Oil is not soluble in water, therefore tiny globules of oil is formed & suspended in water. Emulsifier is used for breaking of oils into tiny particles and made the emulsion. Thus emulsion is used in metal cutting operation so that oil act as lubricant and water performs

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cooling action [18]. Such water soluble cutting fluids are classified as:

i. Synthetic cutting fluid
ii. Semi synthetic cutting fluid
iii. Vegetable oil based cutting fluids
iv. Soluble cutting fluid

i. Synthetic cutting fluids: Synthetic cutting fluids contain soluble lubricants, high pressure additives, corrosion inhibitors, biocides, surfactants and deformer. The composition of synthetic cutting fluids does not have mineral oils. They form a solution with water and has lower lubrication effectiveness and suitable for low force application.

ii. Semi synthetic cutting fluids: Semi- synthetic cutting fluids are better lubricating effect than synthetic cutting fluids. They are more effective in corrosion or oxidation prevention. Semi-synthetic cutting fluids contain both mineral oils and chemical additives.

Major limitation with this kind of cutting fluid is that they can cause serious health problems like cancer, skin diseases, and respiratory diseases due to their toxicity to the person which is constantly working with these cutting fluids. Their untreated disposal is also harmful for air, soil, ground water and subsequently agricultural product.

iii. Vegetable oil based cutting fluids: Vegetable oil based cutting fluids refers to the oils basically extracted from trees or vegetables like Sunflower oil, Coconut oil, Palm oil, Ground nut oil etc. These are

environmental friendly cutting fluids results better performance than mineral based cutting fluid and straight oil [9,19-21]. The biodegradability, renewability and less toxic property of vegetable oil based cutting fluids make them as a better substitute for petroleum based cutting fluids and synthetic fluids.

iv. Soluble cutting fluids: The soluble oils have lubrication and corrosion prevention characteristics of mineral oils, together with the cooling effect of water. Soluble oils consist of a mineral oil accompanied with emulsifiers which allow the oil to be dispersed into the water in proportion that varies from 1:10 to 1:100 [22, 23], so that they have characteristics of both mineral oils and water. They contain the lubrication & rust prevention property of mineral oils and cooling effect of water.

(d) Paste and Solid Lubricants: Waxes, pastes, soaps, graphite and molybdenum disulphide are some examples falling into this category. These are generally applied directly to the work piece or tool or in some cases impregnated directly into the tool, for example the grinding wheel of a grinder. One example of a paste lubricant is lard. Many experienced journeymen recommend lard for tapping.

Effect of Cutting fluid on machining parameters:

Cutting Fluid	Machining Process	Workpiece Material	Findings	Reference
Water	Turning	Mild Steel	Workpiece temperature after turning at 355 rpm with HSS cutting tool is 33^{0}c while with carbide cutting tool it is 34^{0}c. Hardness of specimen is 211 BHN with HSS cutting tool while 194 BHN with carbide cutting tool.	24
Palm Kernel Oil	Turning	Mild Steel	Workpiece temperature after turning at 355 rpm with HSS cutting tool is 36^{0}c while with carbide cutting tool it is 38^{0}c. Hardness of specimen is 187 BHN with HSS cutting tool while 173 BHN with carbide cutting tool.	24
Soluble oil	Turning	Mild Steel	Workpiece temperature after turning at 355 rpm with HSS cutting tool is 34^{0}c while with carbide cutting tool it is 32.5^{0}c. Hardness of specimen is 187 BHN with HSS cutting tool while 167 BHN with carbide cutting tool.	24
Dry	Turning	Mild Steel	Workpiece temperature after turning at 355 rpm with HSS cutting tool is 37^{0}c while with carbide cutting tool it is 39^{0}c. Hardness of specimen is 210 BHN with HSS cutting tool while 187 BHN with carbide cutting tool.	24
SCF-I*	Drilling	AISI 304	Thrust force is approximately 1250 N and average surface roughness is approximately 1.85 µm (spindle speed is 720 rpm, feed rate is 0.12mm/revolution and drilling depth is 21 mm)	25
SCF-II*	Drilling	AISI 304	Thrust force is approximately 1320 N and average surface roughness is approximately 1.85 µm (spindle speed is 720 rpm, feed rate is 0.12mm/revolution and drilling depth is 21 mm)	25

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CSCF-I*	Drilling	AISI 304	Thrust force is approximately 1305 N and average surface roughness is approximately 1.9 µm (spindle speed is 720 rpm, feed rate is 0.12mm/revolution and drilling depth is 21 mm)	25
CVCF*	Drilling	AISI 304	Thrust force is approximately 1340 N and average surface roughness is approximately 1.85 µm (spindle speed is 720 rpm, feed rate is 0.12mm/revolution and drilling depth is 21 mm)	25
CMCF*	Drilling	AISI 304	Thrust force is approximately 1280 N and average surface roughness is approximately 2.1 µm (spindle speed is 720 rpm, feed rate is 0.12mm/revolution and drilling depth is 21 mm)	25
Dry	Turning	Aluminium	Flank wear with HSS cutting tool is approximately 0.027 mm while with carbide cutting tool it is approximately 0.015 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Brass	Flank wear with HSS cutting tool is approximately 0.039 mm while with carbide cutting tool it is approximately 0.016 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Mild steel	Flank wear with HSS cutting tool is approximately 0.12 mm while with carbide cutting tool it is approximately 0.017 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Medium carbon steel	Flank wear with HSS cutting tool is approximately 0.145 mm while with carbide cutting tool it is approximately 0.05 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
Mentholated Spirit	Turning	Aluminium	Flank wear with HSS cutting tool is approximately 0.02 mm while with carbide cutting tool it is approximately 0.005 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Brass	Flank wear with HSS cutting tool is approximately 0.028 mm while with carbide cutting tool it is approximately 0.006 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Mild steel	Flank wear with HSS cutting tool is approximately 0.03 mm while with carbide cutting tool it is approximately 0.007 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Medium carbon steel	Flank wear with HSS cutting tool is approximately 0.027 mm while with carbide cutting tool it is approximately 0.015 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
Paraffin	Turning	Aluminium	Flank wear with HSS cutting tool is approximately 0.022 mm while with carbide cutting tool it is approximately 0.007 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Brass	Flank wear with HSS cutting tool is approximately 0.031 mm while with carbide cutting tool it is approximately 0.008 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Mild steel	Flank wear with HSS cutting tool is approximately 0.028 mm while with carbide cutting tool it is approximately 0.009 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Medium carbon steel	Flank wear with HSS cutting tool is approximately 0.034 mm while with carbide cutting tool it is approximately 0.03 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
Soluble oil	Turning	Aluminium	Flank wear with HSS cutting tool is approximately 0.006 mm while with carbide cutting tool it is approximately 0.003 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Brass	Flank wear with HSS cutting tool is approximately 0.007 mm while with carbide cutting tool it is approximately 0.004 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Mild steel	Flank wear with HSS cutting tool is approximately 0.009 mm while with carbide cutting tool it is approximately 0.006 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26
		Medium carbon steel	Flank wear with HSS cutting tool is approximately 0.01 mm while with carbide cutting tool it is approximately 0.009 mm (at a speed of 370 rpm, 1mm depth of cut and machining time is 1200 seconds)	26

*CSCF-I: Crude sunflower cutting fluid; SCF-I: sunflower cutting fluid; SCF-II: sunflower cutting fluid (a mixture of two surfactants); CVCF: Commercial vegetable cutting fluid; CMCF: Commercial mineral cutting fluid.

III. CONCLUSION

Any particular cutting fluid doesn't have cooling and lubrication properties suitable for every metal-working application. Effects of different cutting fluids are reviewed. Some important findings are listed below;

- Straight oil may be good lubrication but poor cooling capabilities.
- Water is an effective cooling agent but very poor lubrication and causes rusting.
- Lower thrust force value was obtained with SCF-I.
- SCF-I was the most effective in reducing surface roughness.

- Soluble oil gave minimum flank wear as compared to mentholated spirit, paraffin and dry machining condition.

However cutting fluid improves tool life, surface finish and reduces cost, but its effect on environment is a barrier for its excessive use. Therefore recent techniques like MQL and MQL using nanofluids, which requires less amount of conventional cutting fluid with improved cooling and lubricating effect, got attention of researchers.