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Influence of Cutting Fluid on Machining Processes: A Review

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ABSTRACT

*Machining process in Manufacturing system is the removal of material to produce a desired shape, size and, or weight of a particular part. This involves the use of cutting, grinding and boring tools as the case maybe, the process itself is not free from challenges that includes reduction in tool life which are usually affected and also the effect of friction which affects machine parts. Therefore, an engineering practice in manufacturing system **is** required to eliminate or bring to bare minimum the challenges in this machining processes, hence the cutting fluid technology is researched to be a solution solving process. Cutting fluids are widely used and has been majorly seen as a necessary additive to enhance output and increased quality machining operations. The effect of friction leads to sudden rise in cutting temperature and tool wear during machining which impair the quality of the final product. The highly recognized cooling techniques utilized between the several cooling techniques used in metalworking are nanofluids, cryogenic systems, and cooled trodden air. The utilization of cutting fluids cannot be overlooked during machining process as it forms strong defensive films in the contact territories at low speed, making the grip frailer and averting the creation of stores, hence, lowering friction between two mating parts. The resultant effect of good cutting fluid during machining operation enhanced good surface roughness and better service life of the device and suitable finished surface of workpiece that are subjected to machining operations.*

Keywords: Chip; Cutting Fluids; Lubricant; Machining; Metalworking; Productivity

INTRODUCTION

Technological innovation is the basis for development in manufacturing design which is propelled by development of cutting fluid from petroleum-based products. In other to ascertain anticipated quality, lower construction costs, and output enhancement, metalworking processes must along these lines, therefore experience changes in order to meet market necessities (Taleghani 2021). The type of cutting fluid employed during machining plays a significant role in improving the machining performance if is being chosen, prepared, utilised, handled and disposed appropriately (Agrawal & Patil 2018). One of the major processes in mechanical engineering is metal cutting which involves high speed metalworking, deformation (plastic) of material heat generation, mechanical and thermal stresses. Due to cooling and lubricating effect, the utilisation of cutting fluid cannot be overemphasized (Araújo et al. 2019). Water was used by F.W. Taylor just because during the twentieth Century to cool the machining procedure and observed that there was an increase in tool life. Hence, water is associated with limitations like low lubricating effect and its predisposition to cause initiate oxidation and rust, various large cutting fluids has been used with different methods of application and other purposes (Benedicto et al. 2017). Nevertheless, in the most recent decade, much has been done pointing the restriction of the application of cutting liquids in metal working as a result of the economic implication of the liquids, environmental issues, human wellbeing, etc. Cutting fluids are also used to lessen the rate of wear of the device and enhance the value of the exterior portion of the workpieces (Hosseini et al. 2020). They perform several specific functions, such as cooling, lubrication, low friction coefficient, enhancement in the surface condition, the passage of chips from the machining zone, momentary protection of the product against corrosion, the extension of tool life, an enhancement in the value of industrial products and the efficiency of the machining process, low cutting force, and a reduction in workpiece deformation (Hosseini et al. 2020; Madanchi et al. 2015). In addition, cutting fluid has a great cooling effect in high speed machining processes. Hence, the heat produced in the cutting region during machining process has an undisputable operating effect on the dimensional precision of the workpiece and tool life (Irani et al. 2005). The inappropriate usage of the cutting fluid can result to production of heat in metalworking process which will affect the cutting forces, mechanical properties of materials and tool failure.

Cutting fluid has a great luricating/cooling effect in high speed machining processes. The tiny parts or layers of removed material produced during machining process are known as chip. The chip embrittlement becomes easier for chip breaking with the application of cutting fluid. Khanna, et al. (2021) reported that sustainable production is ensured through the use of cutting fluid shown in Figure 1 which provide cooling accessible to the different areas on the workpiece. Majorly at the tool tip and cutting edge, it takes away heat from the cutting territories and lowers the degree of hotness in device and workpiece. This can result to production of heat in metalworking process (Madanchi et al. 2015).

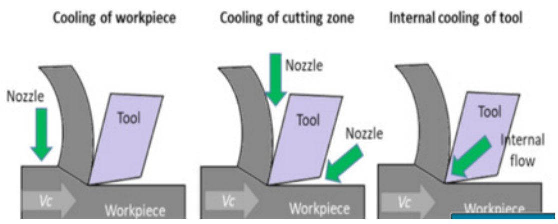

FIGURE 1. Different accessible cooling areas on the workpiece (Khanna et al. 2021)

Different heat transfer methods such as conduction, convection, evaporation, vaporization, and little of radiation bring about chilling effect. Reduction in heat, chemical response, material grip of the device and its lifespan is prolonged through the application of cutting fluid. The thermal expansion of machining system is inhibited thereby lowering the thermal warp of work piece and its dimension precision is enhanced (Jun et al. 2017). Indigenously, cutting fluid was utilized to improve the cooling and lubrication of an engine. Figure 2 shows the lubrication and cooling approach commonly associated with machining process. The application of cutting fluid, usually enhances the economy of device and it gets simpler to maintain uptight resistances and to keep workpiece surface features without harms. Nevertheless, a few issues like liquid residuals and human illnesses are additionally appended to their utilization.

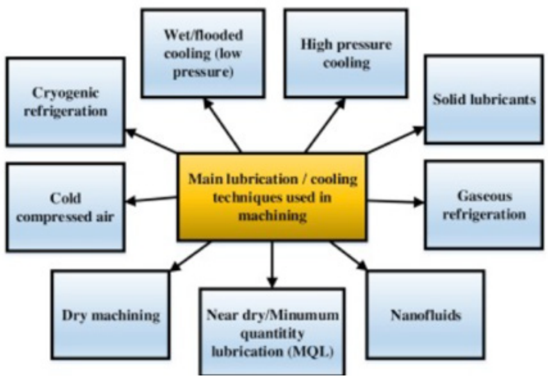

FIGURE 2. Lubrication and cooling techniques in machining (Shokrani et al. 2012)

The cost, environmental and health effect posed a serious problem in the application of cutting liquids during machining processes (Benedicto et al. 2017). However, provision has been made for some substitutes to overcome the major problems or still eradicate the utilization of cutting liquid in machining processes.

MACHINING PROCESSES

Machining is a procedure that manages the expulsion of metals as chips using one or numerous wedge-formed cutting devices (Madanchi et al. 2019). Parts produced by forming, casting and diverse key machining forms frequently require extra activities before the final use or assembly. Metalworking procedures, for example, milling, cutting, turning, or grinding of materials involves the utilization of cutting liquids to take away heat between the workpiece and the cutting devices and lessen friction and wear. The workpiece material and use of complete portion determine the selection of metalworking process which also depends on operative performance called as production cost. Different product parts are machined off as unnecessary material from job or work piece through machining processes. These are carried out using machine tools in manufacturing industry (Madanchi et al. 2015).

TURNING PROCESS

An unwanted material is discarded from the revolving part through turning operation. It is the order of operations done by the machines on unprocessed materials which is to be converted into incomplete or finishing part that depends on utilization. Different product parts are machined off as unnecessary material from job or work piece through machining processes. Turning operation with many features is used to produce a typical axisymmetric part in rotational manner. Industrialization and technological advancement must be improved in engineering sector for better product, quality and of materials economical sustainability (Agrawal & Patil 2018). It was discovered that when turning toughened 52100 steel with cubic boron nitride devices at reasonable cutting speeds (110m/min), the flank wear produced by dry cutting was low, while pointing a compressed air plane at the cutting region resulted to maximum flankwear (Ni et al. 2019).

CRUSHING METHOD

Cutting force acts straight on work exteriors therefore making outer impact on the energies system of the standing table during milling process. Maintaining precision and value of the finishing workpiece and creating a workable metalworking process, the compensation must be made to that effect (Peña-parás et al. 2019). Construction of parts in most metal processed factories like automobile, aerospace etc requires milling process which is the general conventional method of removing metal. Cutting procedure and cutting power influences the efficiency of the cutting performance. There is an existence of cutting force in any machine tool application during cutting process. The quality of the cut and tool life is affected by the cutting force (Mundrathi & Ravalia 2019).

GRINDING PROCESS

The process of grinding requires single coarse grain as a cutting device. Along the outside edge of the wheel, the coarse grains are separated erratically and have unequal shapes. Grinding chips go through much bigger plastic warp compare other metalworking processes with an average rake angle of the grain. Grains are not all lively on the wheel and the surface speeds are very high. Due to the smaller dimensions involved in machining operations, the forces in grinding are smaller. Forces in grinding are lesser than those in machining operations due to lesser measurements involved but little grinding forces are suggested for dimensional precision. The major parameters that affect it are grinding deepness, ‘a’, grinding helm diameter, ‘ds’, surface speed of the grinding helm, ‘vs’, surface speed of the workpiece, ‘vw’, diameter of the piece, ‘dw’, dimension of the tiny layer material, ‘lc’, and flux of heat produced by the cut, ‘q’ (Jia et al. 2016).

DRILLING PROCESS

Boring is one of the metalworking processes of creating rounded aperture in the workpiece by means of a revolving cutter known as drill. Drilling process covers the 25 % of total machining time as reported (Suresh Kumar et al. 2019). Drilling is broadly utilised in machining process and has substantial economic benefit since it is part of the finishing stages in the construction of mechanical works. According to (Yan et al. 2016), in boring operation the tool geometry and plastic warp of workpiece material are complex. In boring process, the cutting speed amount to zero at the tool midpoint. The cutting rate and rake position differ with respect to the space from the boring midpoint and the cutting edge has the peak cutting rate known as the marginal cutting velocity. The removal of the material occurs as extrusion process due to the difference in the cutting speed. Usually, drills are formed by two steps are involved in the formation of drills which are, first one is the penetration of drill point angle into the workpiece, subsequent step is boring of hole (Yan et al. 2016).

CHARACTERISTICS OF CUTTING FLUID

VISCOSITY AND DENSITY

The common properties of cutting liquids that reveals inner resistance, warmth and mass exchange properties are viscosity and density which have enormous effect on oiling, cleaning and cooling state of cutting area. Specific heat is an essential factor that characterizes the cooling and heat exchange efficiency of cutting liquids (Zhang et al. 2011). The stability and distribution of cutting liquids indicate the separation period of the segments in cutting liquid, SS.

PERMEABILITY AND WETTABILITY

Permeability and wettability of cutting fluids plays a major function for lubrication, cooling and cleaning, at a high turning rate of grinding cutting plate while the contacting time of disc and workpiece is shorter than 1ms. Requirements for wettability and permeability will further increase when atomization utilisation of the cutting liquid is carried out in a little quantity. The wettability and porousness of our cutting fluids can be evaluated using the wetting point and its variety ratio (Lawal et al. 2013).

CUTTING FLUID

The exploit of cutting liquid has been in existence from the olden days. Generally, people see the application of water as shown in Figure 3 as the key factor to advance the efficiency and quality of stone polishing, bronze, or iron. Vegetables and animals were majorly used as oil-based lubricants ever since 16^{th} century. The use of cutting liquid as shown in Figure 3 for cutting steel in large quantity is an advanced industrial revolution as a result of the materialization of different machine tools (Raju et al. 2020).

FIGURE 3. The use of cutting fluid for steel projects (Wasatch steel cutting, 2021)

TYPES OF CUTTING LIQUID

In machining cutting fluids act as lubricant, coolant, rust inhibitors and chip disposer Since machined components parts commonly transmit lubricant and soil particles along with them cleaning and arrangement of the processed component must be done. This specific function of cutting fluid supersedes other functions such as removal of heat from workpiece and the cutting region, discarding the tiny layers of material from the cutting area, averting erosion and greasing the edge of the chip and tool, also the tool and work piece (Raju et al. 2020). It lowers temperatures in the cutting zone, lowers forces, enhancing device life and chip brittleness. The optimal value of cutting fluid pressure and stream rate must be used to improve the machinability therefore, it is important to discover the ideal estimations of these parameters. Cutting liquids are commonly grouped into three significant groups which include: (a) Vapors (b) Neat cutting lubricants (c) Water-solvent cutting lubricant.
The composition of cutting fluid, its impact on the exterior of the workpiece, and its movement into the interaction region are very important factors that determine the performance of the cutting fluid (Suresh Kumar et al. 2019).

GASES

Gas-based Cutting liquid is applied as gas or as cooled pressure liquid. At room temperature the substances are majorly found in form of gas typically we have Nitrogen, Argon, Helium, and Carbon dioxide as Gaseous Cutting liquids. Most metalworking processes do not require liquid coolants due to the danger of oxidization incidence on workpiece or engine part, vaporous cutting liquids are valuable in such condition. The utilization of vaporous cutting liquid is costly and limited since it cannot be reused.

NEAT CUTTING OIL

Neat cutting oils are fluids generally dependent on mineral oils and utilized for cutting without including water for example as provided by the producer. They are usually blend of mineral oils and other additives. Neat oils can be used for applications from simple metalworking to heavyweight machining procedures, like, gear hobbing, broaching, turning, honing, and drilling. Cutting fluid produced from mineral oil or petroleum by products is not usually environmentally friendly but has an excellent performance in machining operations. This cutting fluid is hazardous to life of living beings and causes pollutions.

WATER SOLUBLE CUTTING FLUIDS

Dissolvable oils are metalworking liquid concentrates containing a significant level of lubricant (typically above 50%). An emulsion that has a creamy appearance is formed when mixed with water. The high oil content gives great physical lubricity to the cutting procedure just as guard for the machine device. The main objective of cutting liquid is to remove heat from the cutting region by conduction method, accordingly, in like manner it is significant for cooling that the cutting liquid must have high warm conductivity and explicit heat. Categorically, the highest suitable coolant liquid with reduced together with increase conductivity and specific heat is water. Water soluble oils, have excellent performance at quite high cutting speeds compare to neat oils, where heat production and high temperatures are a limitation (Suresh Kumar et al. 2019). They require dilution with water before application since they are generally provided as concentrates.

Such water-miscible cutting liquids are grouped into the following: Artificial cutting fluid, Semi-synthetic cutting fluid, Vegetable-based cutting fluids, and Solvent cutting fluid.

1. Artificial cutting liquids - Artificial cutting liquids contain dissolvable oils, high-pressure added substances, oxidation enzymes, explosive materials, surface active substances, and deformers (Kumar & Ravi (2021). The arrangement of manufactured cutting liquids doesn't have inorganic oils. They structure an answer with water and have little oil viability and appropriate for small power application.
2. Semi-synthetic cutting liquids – Semi-manufactured cutting liquids are preferable lubricant over non-natural cutting liquids contain both mineral oils and chemical constituents. They are progressively effective and valuable in corrosion or oxidation counteraction. It contains both mineral oils and synthetic added substances. Severe health problems are attached to the use of semi- synthetic fluids such as malignant

growth, skin sicknesses, and lung maladies as a result of hazardous effect on the individual who is continually handling these cutting liquids.

3. Vegetable-based cutting liquids - Vegetable based cutting liquids is significantly separated from plants or vegetables like sunflower based, coconut oil, palm oil, groundnut oil, and so on. They are natural agreeable cutting liquids leads to preferable performance over mineral-based cutting liquid and straight oil. The biodegradability, inexhaustibility, and less contaminated of vegetable-based cutting liquids improve them being a substitution for oil-based cutting liquids and manufactured liquids. The use of vegetable based cutting fluid does not involve emission of toxic gases, environmentally friendly and makes provision for worker's safety and it is nonhazardous (Kumar & Ravi (2021). Commonly, oil-based cutting fluid is a combination of oil and water which protects metals from rusting and has more cooling ability than straight oil.
4. Solvent cutting liquids - The dissolvable oils have oil oxidation prevention features of mineral oils, just as the cooling impact of water. Dissolvable oils comprise of a inorganic oil joined by emulsifiers which give space for the lubricant to be scattered into the water in the proportion that changes from 1:10 to 1:100. With the goal that they have highlights of both mineral oils and water. Soluble cutting fluids are most preferred based on the industrial relevance or application area of cutting liquids, like, cost, reuse, natural risks, and removal, and so forth (Kumar & Ravi (2021).

The sort of grease/coolantsystem and the suitable technique for application determines the comparison of the cutting fluid as shown in Table 1. The grouping can also be determined by the the kind of lubricant or the type of system distinctly as seen in Table 2. The cutting parameter like depth of cut, cutting feed, speed, and cutting fluid has been changed and in each case surface roughness wear is measured.

TABLE 1. Comparative analysis of conventional cutting fluids and vegetable based cutting fluids (Agrawal, & Patil 2018).

Run					Tool wear		Tool wear	
	V	F	D	Ra (Micron)	Conventional cutting fluid (Weight loss)gm		Vegetable based cutting fluid (Weight loss)gm	
	Rpm	mm/rev	mm		Before	After	Before	After
1.	500	0.18	0.2	3.1	6.71	6.71	6.71	6.70
2.	500	0.27	0.4	3.7	6.71	6.69	6.70	6.70
3.	500	0.36	0.6	5.1	6.69	6.68	6.70	6.69
4.	800	0.18	0.4	5.5	6.68	6.68	6.69	6.67
5.	800	0.27	0.6	2.8	6.68	6.67	6.67	6.67
6.	800	0.36	0.2	4.4	6.67	6.65	6.67	6.67
7.	1250	0.18	0.6	2.0	6.65	6.65	6.67	6.66
8.	1250	0.27	0.2	3.2	6.65	6.64	6.66	6.65
9.	1250	0.36	0.4	2.8	6.64	6.62	6.65	0.64

TABLE 2 Cutting fluids best for different metals and machining operations (Kumar & Ravi 2021)

Operation	Work Materials						
	Alloy steel	Malleable Iron	Cost Iron	Copper	Bronze	Brass	Aluminium
Trimming	Soluble Oil	Soluble Oil	Dry	Soluble Oil	Soluble Oil	Soluble Oil	Soluble Oil
			Soluble Oil				
Drilling	Soluble Oil	Dry	Dry	Dry	Dry	Dry	Soluble oil
	Sulphurised Oil	Soda Water	Air jet	Soluble Oil	Soluble oil	Soluble oil	Kerosene
	Mineral Lard Oil		Soluble Oil	Mineral lard oil	Lard oil		
				Kerosene			

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Reaming	Soluble Oil	Dry	Dry	Soluble Oil	Dry	Dry	Soluble oil
	Sulphurised Oil	Soda Water	Soluble oil	lard oil	Soluble oil	Soluble oil	Kerosene
	Mineral Lard Oil		Mineral oil Lard oil		Mineral oil		Mineral oil
Threading	Sulphurised Oil	Lard oil	Dry	Soluble Oil	Soluble oil	Soluble oil	Soluble oil
	Lard Oil	Soda Water	Solphurised oil	lard oil	Lard oil	Lard oil	Kerosene Lard oil
Milling	Soluble Oil	Dry	Dry	Dry	Dry	Dry	Dry
	Mineral Lard Oil	Soda Water	Soluble oil	Soluble Oil	Soluble oil Mineral oil	Soluble oil	Soluble oil Lard oil Mineral oil

APPLICATION OF CUTTING FLUIDS

Different methods are employed for the use of cutting liquid, the most widely recognized is by the flood. This technique allows a consistent flow of cutting liquid to the device and the workpiece. It requires various parts in the system, majorly channels, a distribution framework, funnels, and spouts, and oil recuperation gadgets (Irani et al. 2005). Other application techniques are by fog, where the liquid is applied by pressurized airstream at high speed; and high-pressure framework, where the liquid is provided at 5.5 to 35 MPa, that permits expanding heat expulsion and conveyance of the tiny layers of material. The use of cutting fluid is essential while cutting with low-quality devices, like high speed steels. Usually, cutting fluid will remove higher levels of heat produced from the cutting interface and less friction, as well as lowering the cutting forces (de Oliveira et al. 2020). This will leave a workpiece with an improved surface finish and advanced dimensional accuracy. This is because of the warmth delivered during cutting which increases very much the device temperature, lowering its mechanical strength and, subsequently, enabling the rate of plastic distortion easier and total breakdown. Cutting fluids enables the utilization of generally high cutting rates, lowers the temperature by not permitting the tool to lose its strength. The utilization of cutting liquids is important in various processes like boring, broaching, milling, threading with high speed steel devices. Clean environment requires appropriate performance of viable metal working procedures in an efficient manner. The manufacturing industry with the present cooling/lubricating methodologies have offered workable solutions that allow economic growth and natural environment (Singh et al. 2020).

Problems of Cutting Liquid

The specific reason for cutting liquid in metalworking processes is decreasing the friction wear and the cutting temperature through cooling or lubrication as a result of heat conduction. The ecological and well-being impacts with the expenses incurred during the application, care, and discarding are the main shortcomings associated with the cutting liquids (Shokrani et al. 2012). Yıldırım, et al. (2020) reported that the forms of failure associated with cutting tools, such as flaking and cracking are controlled when cutting fluids are being employed as a result of their lubrication, cooling and chip flushing abilities. However, the environment is affected while the workers are vulnerable to health issues through contamination. The reduction in the use of cutting fluid has led to a means of conserving the cost of the coolant/lubricant and cost of maintaining workpiece/tool/machine. Environmentally, many of the regular cutting liquids are non-biodegradable and toxic in nature. Moreover, the expense of disposing them is very high. The cost implication of the cutting liquids includes the expense of purchase, preparation cost of the cutting fluid, maintenance and cost of discarding them. Majorly, cutting liquids are not recyclable in nature, therefore, it is important to treat the cutting liquids before discarding. The treatments of cutting fluid before discarding is costly and influence the removal cost an excess of which can be up to two or multiple times their expense of purchase (Sharma & Sharma, 2014). Hence, the summary of the significant effect of cutting fluid on the environment is shown in Table 3. The growth of public health concern in the world as a result of the use of conventional cutting fluid led to the following restrictions towards conventional cutting fluids:

1. Breaking-up of cutting fluid at high shear usually result in environmental pollution.
2. Operators encounter skin and respiratory that is, biological (dermatological) problem when handling cutting fluid.
3. Soil pollution and water contamination while discarding the cutting fluid is experienced.
4. Environmental regulations become complex to meet up with and the cost of discarding the cutting fluid increased.
5. More ground space and structure for storing, pumping, refining, cooling and recycling becomes necessary (Fang & Obikawa, 2020).

TABLE 3. Significant effect of cutting fluid on the environment (Krolczyk et al. 2019).

Effect	Performance result	Energy	Cost	Ecosystem
Positive				
	Production Dirt-free chip	No energy consumption for coolant system	Reduction in Total cost of producing a part	No soil or water contamination (environment)
	No use of cutting fluids – hence no pump or additional setup is needed		Cost of coolant is zero	Clean chip cause ease of recycling
	Need for high performance tool coating		Cost of coolant setup is zero	
Negative				
	Increased temperature	High energy consumption due to higher cutting force requirement	Overall cost increases for difficult-to-cut materials	Increased temperature - hot ambient condition
	Rise in failure modes of tool, reduction in the service life of tool			Discharge of metal particle
	Bad surface finish			Proper ventilation

Solution to Problems

The Technological Advancement has brought out so many solutions to the problem of environmental contamination in manufacturing industries. Hence, the idea of green cutting is projected, which considers health of human beings as priority and being secured also leaving the environment free from pollution. Cutting liquid is among the key factors used for optimizing machine parameters i.e., reduced surface coarseness, needed material evacuation rate so as to lower material wastage rate. Twari et al. 2020, noted that improved cooling skills are necessary in order to thoroughly lower the thermally-induced wear and prolong service tool life. Cutting liquid is very important in machining industries, because productivity and machinability with improved quality are enhanced with cutting fluid. The increase in productivity and machinability is a function of improved tool life, surface finish, and accuracy to size, make chip breaking and chip transfer easier. Figure 4 displays the graph (plot) of the effect of cutting fluid on tool life.

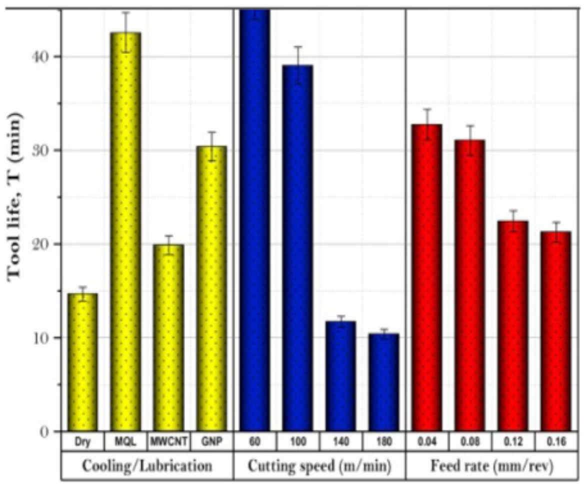

FIGURE 4. The influence of cutting fluid on tool life. (Kıvak et al. 2020).

Harmful impacts, ecological and health effects are the drawbacks related with the utilization of cutting fluid. Conserving the use of cutting liquid is significant as a result of cost effect that is involved in their application, cleaning cycle time of the machine and disposal. Therefore, cost has to be analysed in order to appraise the sustainability of these fluids in manufacturing industry (Pereira, et al. 2017). Synthesis and contemporary application of nano-fluids are being investigated by designers and manufacturers due to the fact that they are cost effective and environmental-friendly (Singh et al. 2017). The locally prepared eco-friendly vegetable based with minimum quantity cutting fluid has progressively substitute the mineral oil since the method can proffer solution to the problem of health hazards (Gajrani et al. 2019). Maintaining the low temperatures of the cutting fluid enhances the lifespan of the liquid, conserving its properties and qualities. An optimum machining conditions can be assessed by employing Taguchi based Grey Relational Analysis (Rapeti et al. 2018).

CONCLUSIONS

Cutting liquid is among the key factors used for optimizing machine parameters i.e., reduced surface coarseness, needed material evacuation rate so as to lower material wastage rate and enhance surface integrity. The major ingredient used for both vegetables based cutting liquid and regular cutting fluid which is dissolvable type is groundnut oil. Cutting liquid is very important in machining industries. Productivity and machinability with improved quality product are enhanced with cutting fluid. The increase in productivity and machinability is a function of improved tool life, surface finish, and accuracy to size and make chip breaking and chip transfer easier. Hazardous effects, environmental and health impacts are the problems associated with the use of cutting fluid. The best use of cutting liquid is important due to the cost involved in their application, maintenance and disposal. Maintaining the low temperatures of the cutting fluid enhances the lifespan of the liquid, conserving its properties and qualities. The study reviewed that identifying a cutting fluid which balances industrial, environmental and economic requirements of a particular machining process becomes essential. Hence, there is need for the development of novel cutting fluids with excellent performance in order to measure up with the rise in economic growth, improved materials, and innovative machining methods.

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DECLARATION OF COMPETING INTEREST

None

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