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Cutting Fluids and Cutting Fluid Application Techniques in Machining: A Review

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Abstract— In view of the environmental and health hazards associated with the use of conventional cutting fluids together with developing governmental regulations, the cutting fluid type and cutting fluid application techniques are critically important in machining process. The heat generation and temperature at the cutting zone due to the friction at tool-chip interface and tool-workpiece interface are significant parameters which influence tool wear, tool life, surface integrity, chip formation mechanism and hence machining quality. A good understanding of the type of cutting fluid and methods to apply cutting fluid at the cutting zone significantly reduces the heat generation and temperature in machining process improves the tool life and surface integrity. Cutting fluid related costs and health concerns associated with exposure to cutting fluid mist and a growing desire to achieve environmental sustainability in manufacturing lead to re-examine the role of these fluids and quantify their benefits. In this paper, an overview of cutting fluid and its various alternative application methods such as dry cutting, high pressure cooling (HPC), minimum quantity lubrication (MQL) and cryogenic cooling is well presented. These techniques largely minimized the amount of cutting fluids used in machining while providing similar or even better cutting performances compared to wet cooling methods.

Index Terms— Vegetable-based cutting fluids; Dry cutting; MQL; High Pressure Cooling; Cryogenic cooling; Cutting fluids; Application methods**.**

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1 INTRODUCTION

IN Cutting fluids are widely used in machining processes. The main functions of cutting fluid are cooling, lubrication, removing the chips and protecting the workpiece [1]. The cutting fluids is essential in a machining operation in order to enhance the productivity in terms of performances [2]. The use of cutting fluid in machining processes increases the tool life, dimensional accuracy and surface integrity [3]. The utility of cutting fluids has linked with some drawbacks such as their cost, environmental impact and health hazards. The use of Cutting Fluids (CFs) in machining operations is being enquired for environmental and economic reasons. The cutting fluid (Mineral-based) needs physical or chemical treatment by an environmental protection agency in order to remove the hazardous and toxic components before its disposal. The total cost of cutting fluids, including its disposal cost is approximately 17 % of the total machining costs of a product. In recent years, new cutting fluid and cutting fluid application methods have been developed to overcome the main drawbacks of cutting fluids [4, 5]. The main alternatives cutting fluid application methods are dry machining, minimum quantity lubrication (MQL), high pressure cooling (HPC) and cryogenic cooling. However, there is need to understand the technical, economic and environmental aspects of cutting fluid and its application methods in various machining processes.

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2 CONVENTIONAL CUTTING FLUID IN MACHINI

The cutting fluids are primarily classified as straight oils and water soluble oils [6]. Straight oils are used to decrease the friction between the tool-chip-workpiece interfaces. Straight oils have excellent lubrication and corrosion resistance properties but poor cooling capacity [7]. Straight oils are more effective in low cutting speed operations and tend to lose their effectiveness at high speeds. Water soluble oils are more effective at relatively high cutting speeds, where heat generation and high temperatures are the main issues [8]. The water content in soluble oil increases the specific heat and thermal conductivity and allows the coolant to remove heat from the machining process, thus reducing the temperature [3]. However, water content induce corrosion, bacteria growth and evaporation losses [6]. These fluids generally contain emulsifiers which provide good cleaning properties, although they may have foam tendencies, which can inhibit heat transfer. In addition, water soluble oils are non-flammable and its tendency to form aerosols is lower than that of neat oils [9]. Water soluble oils can be classified according to the oil content in [10]: emulsions, semi-synthetic fluids and synthetic fluids. Emulsions and micro emulsions with oil content greater than 40% provide lubricity and better corrosion protection than fluids with higher water content. Semi-synthetic fluids are emulsions with less than 40% of oil and additives, emulsified in water. Synthetic fluids are different from emulsions and semi-synthetic cutting fluid, they have the greater cooling effect and least sensitive to water hardness. Synthetic fluids are oil free transparent cutting fluids that allows good visibility during machining. Cutting fluids can be applied by different methods, the most common conventional method is by flood. This method provides a continuous cutting fluid flow to the tool and the workpiece. It needs several components in the system, mainly filters, a recirculation system, pipes and nozzles and oil recovery device [9].

3 Cutting Fluids Application Method for Machining

3.1 Dry Machining

In dry machining, the cutting fluids is not used during the machining process. Dry machining method is used to avoid the problems related with the use of cutting fluid such as environmental pollution, health hazard and safety consequences. The special coated carbide cutting tools are developed for the use in dry machining. Dry machining is carried out at lower cutting speeds in order to increase the tool life, which in turn increases the production rate [13]. The heat generation at tool-chip interface in dry machining leads to overheating the tool. The friction between the tool and workpiece during dry machining considerably increases the temperature in higher level of abrasion, diffusion and oxidation. Also the heat generation between tool and workpiece due to friction causes the dimensional deviation and metallurgical changes in the workpiece [14]. The chip formation, which could cause deterioration on the machined surface is unable to wash away. Thus, the cutting fluid cannot be completely eliminated in machining process [15].

3.2 High Pressure Cooling Technique

The high-pressure cutting fluid application method is used for better penetration of cutting fluid at tool-chip and tool-workpiece interface. Penetration of cutting fluid at high pressure, in turn reduce the tool-chip contact length and hence removal of heat from cutting zone, where heat generation is important factor which increases with increase in cutting conditions, especially increase of speed and power. The cutting fluid with high pressure (55 to 350 bar) is supplied through designed nozzle, then the jet of cutting fluid with a very high velocity (350 - 500 km/h) impinges between tool-chip-workpiece interfaces. The application of cutting fluid at high pressure allows better penetration of cutting fluid into the tool-chip and tool-workpiece contact area, thus reduces the friction and removes the heat from cutting zone in turn increases the machining process efficiency. This method of cutting fluid application not only reduces the tool wear and improves surface finish but also results in decreasing the contact length significantly [11]. It is very important to filter the cutting fluid to avoid the possibility of containing any tiny particles present in the high pressure jet that deteriorate the surface finish of the workpiece [13]. The HPJA is an efficient method of cutting fluid application providing better chip breakability, reductions in cutting forces, cutting temperature and thermal stresses developed in the tool and workpiece. In high pressure cutting fluid application method there is need to understand the effects of flow parameters along with cutting parameters om responses parameters during the machining operations.

3.3 Minimum Quantity Lubrication (MQL)

Minimum quantity lubrication (MQL) applications is introduced as an environmentally friendly and economically beneficial method [16]. This MQL cutting fluid application method is also known as near dry lubrication. MQL machining is one of the practical ways to the cleaner production in the context of the sustainable manufacturing [17]. In this MQL method, very small amount of mist of air-cutting fluid mixture is applied to the cutting zone. The pressure applied and the flow rates of mist in MQL application method is 6 bar and 50 ml/h - 2 l/h respectively, also the nozzle diameter is 1 mm. The quantity of cutting fluid used in MQL is one ten-thousandth that of the in wet cooling [13]. The cutting fluid is used in such small quantities that it is practically consumed in the process, eliminating the fluid disposal problems. In addition, chips produced are nearly clean from cutting fluid, which are easily recyclable [18]. Some MQL advantages against other lubrication/cooling systems are: reduction of cutting fluid consumption, cost and tool wear; improvement of surface roughness, diminution decrease of the environmental and worker health hazards and improve lubrication than that of the of conventional lubrication/cooling system [19, 20, 21, 22]. MQL is used focusing on the lubricant properties rather than coolant properties, heat removal is achieved mainly by the compressed air [23].

3.4 Cryogenic Machining

Cryogenic machining is new technique such in which nitrogen and helium gas are used as a coolant. Nitrogen is an inert gas and lighter than air. Cryogenic machining is environmentally friendly and safe alternative technique to the conventional flood cooling.. In this technique the nitrogen in a liquid form and at temperature around -200 °C is injected through a nozzle of small diameter into the cutting area. The heat generated during machining process is absorbed by liquid nitrogen and its vapor forms a cushion at tool-chip interface and acts as a lubricant [13]. Additionally, the chips produced by this technique have no residual of oil attached to them and therefore can be recycled as scrap metal. In cryogenic machining volumetric flow rate and pressure of liquid nitrogen are significant parameters for machining performance. Due to the ability of cryogenic fluid of reducing the coefficient of friction at the tool-chip interface, the cutting forces required in cryogenic turning are less than in dry machining. The magnitude of cutting force increases due to overcooling of workpiece and results in to the embrittlement of the workpiece, In cryogenic machining the cooling ability decreases at higher cutting speed as tool-chip contact fully plastic and as cryogenic coolant could not penetrate at interfaces. By proper application liquid nitrogen and controlling its jet parameters, the tool life can be improve significantly [11].

The accuracy of the cryogenic cooling operation decreases as the temperature difference increases and that is the main drawback of this system [24]. Both the liquid nitrogen and the carbon dioxide are needed special set up to reach the cryogenic temperatures needed, cryogenic cooling is an expensive system. [25]. However, despite the high cost of the equipment and the challenges to implement this technique in industrial applications, it is an alternative that may be of particular interest in special operations and particularly when the tool cost is high [26].

4 Conclusion

Cutting fluids play an important role during machining but they use have some drawbacks such as their negative effects over the environment and workers health as by costs associated such as the equipment, fluids purchase and waste fluid treatment. All of these plus governmental regulations are encouraging companies to implement lubrication/cooling systems more efficient and sustainable. The alternative techniques such as dry machining, MQL, High Pressure Cooling (HPC) Cryogenic cooling have been implemented in some machining processes, even may become more efficient than conventional lubrication/cooling. However, there are still applications where cutting fluids cannot be removed.

1. The dry machining is the best method since it eliminates the contamination of cutting fluids in turn health and environment related issues. The high amount of heat is generation and its effects on machining responses has put the limitation on use of this method.. To use this method it is necessary to select appropriate cutting parameters and cutting tool.
2. MQL is an efficient method of cutting fluid application to reduce the negative effects of use of cutting fluid in machining processes such as operator's health and environmental issues. MQL system reduces the fluids use and is a more viable alternative taking into account not only the economic and environmental impact but also the performance. MQL method is applied when dry machining cannot be used or applicable and wet cooling is not desirable.
3. Machining with High Pressure Cooling (HPC) technique results in formation of segmented chips, better penetration at interface and thus lower cutting force, better tool life and acceptable surface finish. It seems to be a potential solution for machining of hard-to-cut materials. Flow rate, Pressure, and the nozzle direction at particular location plays a vital role in machining with HPC.
4. Cryogenic fluid considerably reduces the coefficient of friction at the tool-chip interface, hence it requires less cutting force than in dry machining. Cryogenic cooling can increase the tool life, especially in difficult-to-machine materials. Its environmental impact is lower than other cutting fluids and cutting fluid methods but the it's initial cost is high.

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