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RESEARCH ARTICLE

A REVIEW ON COOLANTS AND THEIR APPLICATION IN DEEP-HOLE DRILLING OPERATION

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ABSTRACT

Deep Hole Drilling involves drilling a hole through the thickness of the component, measuring the diameter of the hole, trepanning (cutting a circular slot around the hole) a core of material from around the hole. During drilling operation, friction between work piece-cutting tool and cutting tool-chip interfaces result high temperature on cutting tool. The effect of this generated heat affects shorter tool life, higher surface roughness and lowers the dimensional sensitiveness of work material. Thus, Increased tool wear being a natural phenomenon in all machining processes leads to tool failure. There is growing demand in machining process for high productivity with use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature. The performances of machining operations are changed by use metal cutting fluids because of their lubrication, cooling and chip flushing functions. Cooling lubrication is an essential condition to achieve the economical tool life and the required surface quality in many cases. As they are used to provide lubrication and cooling effects between cutting tool and work piece and cutting tool and chip during machining operation. Hence the influence of generated heat on cutting tool would be prevented. This paper deals with review on coolants and their application in deep-hole drilling operation.

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INTRODUCTION

Cooling and lubrication are important in reducing the severity of the contact processes at the cutting tool-work piece interfaces. Generally water was used mainly as a coolant due to its high thermal capacity and availability (McCoy, 1994; Machado and Wallbank, 1997). Corrosion of parts and machines and poor lubrication were the drawbacks of such a coolant. Oils were also used at this time as these have much higher lubricity, but the lower cooling ability and high costs restricted this use to low cutting speed machining operations. Finally, it was found that oil added to the water (emulsifying agent) gives good lubrication properties with the good cooling and these became known as the soluble oils. Other substances are also added to these to control problems such as foaming, bacteria and fungi. Oils as lubricants for machining were also developed by adding extreme pressure additives. Today, these two types of cutting fluids (coolants) are known as water emulsifiable oils and straight cutting oils. Additionally, semi-synthetic and synthetic cutting fluids were also developed to improve the performance of many machining operations (Brinksmeier, 1999).

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Thus the cutting fluid plays an important role in chip formation and its removal, tool life, and hole specifications. Water based coolants and their aqueous mixture produced from them such as oil-in-water emulsions or solutions are inferior to the water emulsifiable lubricants, especially in their lubricating effects (El Baradie, 1996). In deep-hole machining, there is a greater demand on the cooling and lubricating properties of the coolants than that in most common machining operations (Popke *et al.,* 1999). Water emulsifiable oils can only be used in exceptional cases as in machining of easy machining materials under light cutting conditions. Deep hole drilling coolants must therefore be made in such a way that they will form coherent lubricating films under the high contact pressure and temperatures at the cutting edge of the tool, the chamfer, and the guide (supporting) pads.

Metallic contact in these regions should be reduced to its possible minimum to avoid seizing. Liquid lubricants, especially mineral oils without additives, cannot fulfill these duties with the desired results under present-day requirements (El Baradie, 1996). Under mentioned high contact pressures and temperatures, any solid lubricant film can separate the contact surfaces reducing friction and wear. These pressure-resistant films are produced by additives, which are blended into the oils. The basic task of these additives is to react chemically with the materials involved, and to form intermediate layers of high compressive and low shear strengths which act as solid or plastic lubricating films. These reactions should only take place at certain temperatures of the contact surfaces. At room temperature, the additives must not react with the tool, the surface of the hole being drilled, the components of the machine and its slide ways. When water emulsifiable oils are used, especially when high stresses and temperatures exist between the contact surfaces, steam bubbles can form on the working surfaces of the cutting tool. Collapsing of steam bubbles produces a quenching effect by the incoming coolant. This shock-like cooling process leads to the formation of cracks and thus leads to premature failure of the cutting edges takes place (Belluco and De Chiffre, 2002). The properly selected, mixed and maintained additives constitute the coolant suitability for a given deep- hole drilling operation. There are a number of such additives available in the market. The polar additives were found very useful (Suryawanshi and Inamdar, 2012). Such additives consist of the molecules containing polar groups. Polar oil molecules are said to be attracted by the metal surfaces so that an orientated and adhesive oil film is produced.

This film has a greater load capacity and also a greater resistance to tearing than a film of untreated coolant. Also, polar additives form metal soaps, which act as high-viscosity plastic lubricant films. These metal soaps, however, have a relatively low melting point of around 120 ^{o}C that makes them less attractive in deep-hole machining of steels. When light metals, such as aluminum, are machined, these soaps may be very useful. As such, these additives affect mainly sliding friction processes in the mixed and boundary friction regions (supporting pads, drill shank, auxiliary flanks). Additives, which are primary intended to prevent seizing, or to reduce it, at high pressures and temperatures, are known as extreme pressure additives (EPA) (Kaminski and Alvelid, 2010). Sculpture, chlorine, and phosphorus are used as EPA in most of deep hole machining coolants. Under high local pressures and temperatures, thermal decomposition of EPA takes place. Corresponding reaction products are formed with the metal sliding on one another as, for example, metallic sulphides, chlorides, and phosphates, which act as solid lubricant films. The higher the cutting speed, the lower viscosity of the cutting fluid should be in order to penetrate into the above discussed cracks formed on the chip free surface. This explains why soluble oils of low viscosity are more efficient at high cutting speeds compare to straight oils.

Types of cutting fluids (Brinksmeier *et al.,* 1999)

There are the five major types of the cutting fluids available today:

Straight Cutting Oils

These are oil-based materials, which generally contain what are called extreme pressure or anti-weld additives. These additives react under pressure and heat to give the oil better lubricating characteristics. These straight cutting oils are most often used undiluted. Occasionally they are diluted with mineral oil, kerosene or mineral seal oil to either reduce the viscosity or the cost.

They will not mix with water and will not form an emulsion with water. The advantages of straight cutting oils are good lubricity, effective anti-seizure qualities, good rust and corrosion protection, and stability. Disadvantages are: poor cooling, mist and smoke formation at high cutting speeds, high initial and disposal cost. Straight oils perform best in heavy duty machining operations and very critical grinding operations where lubricity is very important. These are generally slow speed operations where the cut is extremely heavy. Some examples would include broaching, threading, gear hobbing, gear cutting, tapping, deep hole drilling and gear grinding. Straight oils do not work well in high speed cutting operations because they do not dissipate heat effectively. Because they are not diluted with water and the carryout rate on parts is high, these oils are costly to use and, therefore, only used when other types of cutting fluid are not applicable.

Water Emulsifiable Oils

More commonly referred to as soluble oils. This, however, is a misnomer because they are not really soluble in water but rather form an emulsion when added to water. These emulsifiable oils are oil based concentrates, which contain emulsifiers that allow them to mix with water and form a milky white emulsion. Emulsifiable oils also contain additives similar to those found in straight cutting oils to improve their lubricating properties. They contain rust and corrosion inhibitors and a biocide to help control rancidity problems. Advantages of water emulsifiable oils are:

Good cooling, low viscosity and thus adequate wetting abilities, non-flammable and nontoxic, easy to clean from small chips and wear particles using standard filters, relatively low initial and disposal cost. Disadvantages are: low lubricity, rancidity, misting, low stability (components have different degradation levels), in mass production require everyday expensive maintenance in order to keep the required composition. Water emulsifiable oils are the most popular cutting fluids in use today. Because they combine the lubricating qualities of oil with the cooling properties of water they can be used in a wide range of both machining and grinding operations.

Synthetic Fluids

Sometimes referred to as chemical fluids, these synthetic cutting fluids are water based concentrates, which form a clear or translucent solution when added to water. These fluids contain synthetic water-soluble lubricants, which give them the necessary lubricating properties. In addition, these synthetic fluids contain rust and corrosion inhibitors, biocides, surfactants and defoamers. Synthetic cutting fluids do not contain any oil (Bartz, 2001).

Advantages of synthetic cutting fluids are

Resistance to rancidity, low viscosity and thus good cooling and wetting, good rust protection, little misting problems, non-toxic, completely non-flammable and non-smoking, good filtration with standard filters, biodegradable.

Disadvantages

Insufficient lubricity for heavy duty applications, reaction with non-metal parts, residue is often a problem. As disposal problems become an ever increasing problem with the advent of the Resource Conservation and Recovery Act, synthetic fluids, because they present less of a disposal problem than emulsifiable oils, become more popular because synthetics are easier to treat than emulsifiable oils before they can be disposed. Synthetics are most definitely the products of the future. A very large percentage of the development work on cutting fluids is devoted to improving the synthetic fluid technology. However, there are still some problems and still some machining and grinding operations that for one reason or another cannot be done using a synthetic fluid. The major problem is that lubrication has always been the big problem for synthetic coolants. Another problem caused by synthetics is the sticky and gummy residue that is sometimes left when water evaporates from the solution mix. Metal safety on non-ferrous metals is a problem with some synthetics because of their relatively high pH (8.5 to 10.0) and the lack of oil to act as an inhibitor.

Semi-Synthetic Fluids

These are synthetic fluids, which have up to 25% of oil added to the concentrate. When diluted with water, they form a very fine emulsion that looks very much like a solution, but in fact, is an emulsion. The oil is added to improve lubricity. When synthetic fluids were in their early stages lubricity was a big problem, so the semi-synthetics were introduced. However, with the technology in synthetic lubricants improving, lubricity is not the problem it once was for synthetic fluids and, therefore, the semi-synthetic is becoming less popular.

Liquid nitrogen

Liquid nitrogen (having temperature $-196^{o}C$) is used as a cutting fluid for cutting difficult-to-machine materials where chip formation and chip breaking present a significant problem. Liquid nitrogen is used to cool work piece (for example, internally supplied under pressure in case of tubular-shaped work pieces), to cool the tool (which has the internal channels through which liquid nitrogen is supplied under pressure), or by flooding general cutting area. Although the required properties of the cutting fluid should be formulated for each particular machining operation, some of the qualities required in a good cutting fluid could be listed as (Huang *et al.,* 1999):

(a) Good lubricating qualities to reduce friction and heat generation,
(b) Good cooling action to dissipate the heat effectively that is generated during machining,
(c) Effective anti-adhesion qualities to prevent metal seizure between the chip and the rake face,
(d) Good wetting characteristics which allow the fluid to penetrate better into the contact areas as well as in the cracks,
(e) Should not cause rust and corrosion of the machine components,
(f) Relatively low viscosity fluids to allow metal chips and dirt to settle out,
(g) Resistance to rancidity and to formation of a sticky or gummy residue on parts or machines, (h) stable solution or emulsion, (provide safety work environment (non-misting, not-toxic, non-flammable (smoking),

Should be economical in use, filter and dispose. If there were one product that m*et al*l the particular requirements to the cutting fluid, the selection of a cutting fluid would be easy. But there just is not such a product. Moreover, many of the above-listed properties often cannot be guaranteed without actual testing of a particular cutting tool in a production environment. Such a testing, however, is expensive and time consuming. Therefore, a method to compare different cutting fluids for a particular machining operation should be beneficial. Although a number of attempts to develop such a method, no method has been developed for qualifying and comparing the performance of one cutting fluid to another.

Conclusion

The selection of cutting fluids for machining processes generally provides various benefits such as longer tool life, higher surface finish quality and better dimensional accuracy. These results also offer higher cutting speeds, feed rates and depths of cut. The productivity of machining process will be much higher with combination of selecting higher machining parameters. The material removal rates will be increased. New approaches for reducing cutting fluids application in machining processes have been examined and promising results such as dry machining, advancements on cutting tool materials have been reported. Moreover new coating technologies for various cutting tools have provided important advantages to reduce cutting fluid application in machining operation.

Nevertheless, the machining operations still require the use of cutting fluids in machining of some materials. Therefore, selection of the most suitable cutting fluid in any machining process must be carried out to obtain a maximum benefit. The selection of suitable cutting fluid is affected by mainly three factors in machining operations. These are the types of machining process, work piece materials and cutting tool materials. The combination of these three influential factors would provide basic information for selecting the suitable cutting fluid. The regeneration methods of used cutting fluids would also provide various advantages such as reducing cutting the fluids cost, disposals cost of used cutting fluids and nearly eliminating environmental pollution.

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