EXPERIMENTAL EVALUATION OF THE EFFECT OF MINIMAL QUANTITY LUBRICATION WITH DIFFERENT CUTTING FLUIDS IN DRILLING AISI 4340 STEEL

By

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DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md. Isanul Haque

This work is dedicated

to my loving

Father

&

Mother

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ABSTRACT

Drilling can be described as a process where a multi-point tool is used to remove unwanted materials to produce a desired hole. Its significance has been recognized due to the large Number of holes to be drilled on engineering components and the large amount of costs involved in the process. However, high production machining and drilling with high cutting velocity, feed and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the surface integrity of the product.

The use of minimum quantity lubrication (MQL) in drilling of AISI 4340 steel was studied and the MQL machining performance was compared to dry and conventional flooded conditions. An experimental drilling station with an MQL system was built to measure the amount of Minimum quantities Lubricant uses for drilling. Titanium Nitride coated HSS drill bits of 8.0 mm (diameter) were tested against AISI 4340 Alloy Steel and compared with dry, flood cooling using soluble cutting; VG-68 and MQL using 10-50 ml/h of Vegetable Oil based Olive Oil. The results indicated that the resulted in desirable hole surface and chip segments and the Maximum temperature generated in the work piece during MQL machining was lower than that observed in dry drilling and comparable to flooded conditions. The mechanical properties of the material adjacent to drilled holes as evaluated through hardness measurements. In this case, the Minimum Quantity Lubrication (MQL) is very effective to reduce temperature. When temperature is increased a large amount of tool wear appears at the drill bit. In this situation, high temperature either affects roundness of the hole or chip shape and color of Chip. MQL is applied in the same direction as the drill bit. MQL has reduced temperature as well as improving roundness and also provide lubrication in the tool and surface interface.

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Chapter-1

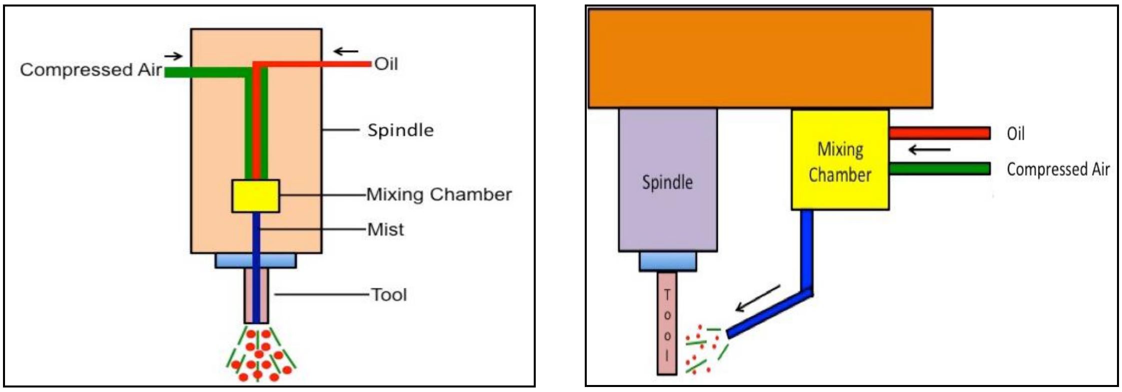
Introduction

Proper selection of cutting fluids generally improves the tool life. Cutting fluid not only cools the tool and job but also provides lubrication and cleans the cutting zone and protects the nascent finished surface from contamination by the harmful gases present in the atmosphere. But the conventional types of cutting fluid have been found to become less effective with the increase in cutting velocity and feed when the cutting fluid cannot properly enter the chip-tool interface to cool and lubricate due to bulk plastic contact of the chip with the tool rake surface [**Ezugwu and Lai Failure 1995**]. Besides that, often in high production machining the cutting fluid may cause premature failure of the cutting tool by fracturing due to close curling of the chips and thermal shocks [**EyupBag˘ and Ozcelik 2006**].

The knowledge over the performance of cutting fluids when applied to different work materials and operations is of crucial importance in order to improve the efficiency of most conventional machining processes [**Degenhardt et al. 2005 and Braga et al 2002**]. This efficiency can be measured, among other parameters, through cutting tool life and work piece surface finish. However, the costs associated with the purchase, handling and disposal of cutting fluids are leading to the development of tool materials and coatings which do not require their application [**Bono and Ni 2006, Sahu et al. 2003**]. In this work, the performance of different types of cutting fluids will be compared to dry cutting in drilling steel using HSS drill bit.

Cutting fluid is used to take away the heat and to lubricate the machined surface. Cutting fluid should promote the tool life, improve the surface integrity of the work piece, flush the chips from the cutting zone and protect the surface from corrosion. Traditionally, the machining of parts uses flood cooling in which the jet of coolant is directed toward the cutting zone. Here, the coolant is deployed in large quantities. There are several disadvantages to using this method. The first one has to do with the cost of machining and its disposal. Approximately fifteen percent of total cost in machining is incurred by the coolant and its disposal [**Quaile et al. 2011**]. The second one deals with a safety issue for the operators. One problem that exists for operators is that when they stay in contact with the coolant for a long time, it may cause skin problems. The third one is the effect on the environment. After machining, the chips produced are mixed with the cutting fluid and they cannot be disposed of directly as regular trash. At the same time, coolant should be filtered before being reused and after several more uses, the coolant also needs to be disposed. The chips and the used coolant are disposed as hazardous waste-a practice that is costly to any industry.

Now, using the coolant in large quantities is a costly proposition that is not user friendly nor environmental friendly. The alternative solution is to machine with a minimum quantity of lubrication (MQL). MQL is also known as near dry machining or spatter lubrication [**Boelkins et al. 2009**]. MQL technique uses a small quantity of oil or lubricant. It is mixed with compressed air to generate a mist or an aerosol. The mist particles provide lubrication and the compressed air helps to reduce the temperature during machining. The range of oil flow rate in MQL usually varies from 1oz to 8oz in 8 hour. This quantity is very small compared to flood cooling. The air pressure varies from 0.2MPa to 6-bar.



Internally applied MQL — Externally applied MQL

Fig.1.1 Internally and externally applied MQL system [**Tejas Maru**]

The selection of the parameters basically depends on the type of tool material, the work piece material and the processes. MQL can be applied through internally or externally. In the internal way of applying MQL is passed through the spindle, tool holder and tool. There are two basic approaches for applying MQL internally. In one method, oil and compressed air are mixed in an external unit and passed through the spindle and tool holder. In the other approach, the oil and the compressed air are mixed inside the spindle and passed through the tool holder. Fig.1.1 shows the internal way of applying MQL, the oil is passed through tool and external way of applying MQL, the oil is passed through an external nozzle with spray form. This system is simple, less expensive and effective for drilling shallow holes and low speed processes like gear cutting and broaching. The benefits of MQL over flood coolant system [**Boelkins**]

- Promotes longer tool life by reducing friction, ranging from 25 to 500 percent.
- Increases productivity in terms of reducing machining time by allowing machining with higher feed rates.
- Chips are clean and dry.
- No need to re-circulate the old or foul smelling coolant
- Minimum disposal cost as mostly mist evaporates during machining.
- Machine as well as machining area remains clean and hence a much safer working area.
- No coolant tank for coolant and no significant filtering system is required.
- The entire process is environmental friendly, as the fluid does not need to be treated, recycled or disposed of.

1.1 Literature Review

Minimum Quantity Lubrication (MQL) is the process of applying a minute amount of a quality lubricant directly in to the cutting tool-work piece interface. This is effective in a variety of metal cutting processes i.e. drilling, tapping, milling and turning. In view of green manufacturing, dry machining has drawn much attention from industries recently. Improvement of tool coating technology has facilitated the complete elimination of cutting fluid in some machining processes. The cutting fluids are still required due to the high friction and adhesion tendency between works and tool materials for difficulty of chip and heat removal.

Minimum quantity lubrication refers to the use of cutting fluids of only a minute amount–typically of a flow rate of 50 to 500 ml/hour–which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition. The concept of minimum quantity lubrication, sometimes referred to as "near dry lubrication" [**Klocke and Eisennbla¨tter 1997**] or "micro lubrication" [**MaClure et al. 2007**], has been suggested since a decade ago as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. The minimization of cutting fluid also leads to economical benefits by way of saving lubricant costs and work piece/tool/machine cleaning cycle time.

MQL is important because the lubricant must be compatible with the environment and resistant to long term usage caused by low consumption [**Wakabayashi et al. 2006**]. In MQL, lubrication is obtained via the lubricant, while a minimum cooling action is achieved by the pressurized air that reaches the tool/work interface. Further, MQL reduces induced thermal shock and helps to increase the work piece surface integrity in situations of high tool pressure (**Attanasio et al. 2006**]

MQL, also known as "Micro lubrication" [**MaClure et al. 2007**] is the latest technique of delivering metal cutting fluid to the tool/work interface. Using this technology, a little fluid, when properly selected and applied, can make a substantial difference in how effectively a tool performs. In conventional operations utilizing flood coolant, cutting fluids are selected mainly on the basis of their contributions to cutting performance. In MQL however, secondary characteristics are important. These include their safety properties, (environment pollution and human contact), biodegradability, oxidation and storage stability.

In May 2007, an article was published by Tech Solve, based on a comparison between flood and micro-lubrication [**MaClure et al. 2007**]. The lubricant used was Experimental vegetable oil based soluble oil (10%). The flow rates used for flood and mist conditions were 1.7 gm/min and 0.0029 gm/min respectively. Experiments were conducted for drilling and milling operations. For the drilling operation the material used was AISI 4340 Steel (32-34 HRC). Speed, feed rate and depth of cut were 55 sfpm, 0.007 ipr and 0.006 inch respectively. The drill used was 0.5 inch heavy duty, oxide coated and high speed steel with a 135° split point. Analysis showed no significant differences in tool life (number of holes to reach end of life criteria) between mist and flood cooling. They were 60 and 61 holes for flood and mist conditions respectively. The average thrust forces were

570 lbs and 447 lbs for flood and mist cooling respectively. For the milling operation the material used was AISI 4140 Steel (24-26 HRC). Speed, feed rate and depth of cut were 400 sfpm, 0.005 ipr and 0.5 inch respectively. The cutter body was RA2 15.44-25 MN25 – 15 C (1 inch diameter) and the cutter insert was R215.44-15T308AAM (grade SM-30 uncoated carbide). Analysis showed little differences in tool life (number of holes to reach end of life criteria) between mist and flood cooling. There were 66 and 80 holes for flood and mist conditions respectively [**MaClure et al. 2007**].

It is showed that MQL helps to reduce the cutting temperature and dimensional inaccuracy when turning of AISI 1040 steel was cut by an uncoated carbide insert by [**Dhar et al. 2006]**. The results obtained in MQL were compared with dry cutting and wet cooling conditions. Different sets of cutting speeds and feed rates were used to compare the effectiveness of dry, wet and MQL cooling conditions. The air pressure of 7-bar and a flow rate of 60 ml/h were used in MQL. Cutting speeds were: 64, 80, 110 and 130 m/min and feed rates were: 0.1, 0.13, 0.16 and 0.2 mm/rev. The effectiveness of the cooling media was observed by measuring the tool-chip interface temperature, the chips' shapes and color, the chip reduction co-efficient and the dimensional deviation at different cutting speeds and feed rates. The tool-chip interface temperature was observed to be the lowest when machining was done with a feed rate of 0.1 mm/rev and a cutting speed of 130 m/min under MQL. When the feed rate was set to 0.2 mm/rev, the temperatures were recorded as 790°C, 775°C and 760°C for dry, wet and MQL conditions respectively. The trend of cutting temperature decreased when the feed rates and cutting speeds were decreased. To determine the dimensional accuracy, the experiment was run at the cutting speed of 110 m/min, a feed rate at 0.2 mm/rev and a depth of cut at 1mm. It was observed that for a cutting length of 425mm, the dimensional deviation was minimum (about 70μm) under MQL and maximum (95μm) under dry cutting condition. The study concluded that MQL provides benefits mainly due to the reduction in cutting temperature, which improves the tool-chip interaction and maintains the sharpness of the cutting edges. MQL reduced tool tip wear and damages and because of this, dimensional accuracy improved.

The effects of MQL in turning AISI 1040 steel at high cutting speeds were investigated again by Dhar et al. [**2006**]. During the experiment the factors: cutting forces, cutting temperature, chip reduction coefficient, average flank wear, auxiliary flank wear, surface finish and dimensional accuracy were measured to see the effect of MQL with different sets of cutting speeds and feed rates. Work material AISI 1040 Cutting tool material Carbide inserts Cutting speed 72, 94, 139 and 164 m/min Feed rate 0.10, 0.13, 0.16, 0.20 mm/rev Depth of cut 1.5mm Air pressure in MQL supply 8 bar Flow rate of MQL supply 200ml/h Cutting environment Dry and MQL method It was observed in the experiment conducted by Dhar et al. that MQL helped to reduce the cutting temperature approximately by 5-10% compared with dry cutting for each combination of cutting speed and feed. The general trend indicates that with an increase in cutting speed, cutting temperature is also increased, but the cutting temperature in MQL is lesser than that of dry cutting. Cutting force and feed force play vital role for power and energy consumption, product quality, and life of other members

The Machining processes have an important place in the traditional production industry. Cost effectiveness of all machining processes has been eagerly investigated. This is mainly affected selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and work piece 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 work piece 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 sensitiveness of work material. This case is more important when machining of difficult-to-cut materials, when more heat would be observed [**Silva and Wallbank 1998**].

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 some 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 **[Brinksmeier et al. 1999, Sokovic and Mijanovic 2001, Bartz 2001, Baradie 1996 and Baradie 1996**].

New approaches for elimination of cutting fluids application in machining processes have been examined and “dry machining” was presented as an important solution [**Sreejith and Ngoi 2000, Popke et al. 1999**]. The development of new cutting tool materials also helped dry machining method to be a positive solution for cutting fluids applications. However, the usage of cutting fluids has been increased due to high production levels in the world. Approximately 2.3x109 liter cutting fluids have been used in the machining operations and its cost value was around $ 2.75x109 [**Popke et al. 1999**].

North America had a big ratio; Europe continent was in the third order after Asia continent [**Popke et al. 1999**]. The first study about cutting fluids had been determined by [**Northcott 1868**] with a book entitled “A treaties on lathes and turning”. In the middle of 1890’s, F.W. Taylor emphasized that using cutting fluids would allow to use higher cutting speeds resulting in longer tool life’s and higher material removal rates [**Avuncan 1998**]. It had been concluded that the application of cutting fluids in machining processes would make shaping process easier [**DeGarmo et al. 1984 and Shaw 1991**].

In early research paper had commented that because of the vast scale on which drilling operations were carried out, even a slight increase in the general level of drill performance would yield important practical and economic benefits to individual firms and the engineering industries as a whole [**Galloway 1957**]. In addition, drilling problems can usually result in costly production waste since most of the drilling operations are the final steps in fabricating a part [**Strenkowski et al. 2004**].

The early types of drills, which were mostly made of rough, flat bars of steel, suffered from a serious chip disposal problem which required frequent interruptions during drilling to clear the chips in order to reach the proposed hole depth. This resulted in low production rate and frequent replacement of worn tools [**Kang 1997**]. As a consequence, the application of the early types of drills was rather limited and numerous attempts had ever been made to seek more efficient drill designs.

The Intensive research works were conducted in the last few years for this reason Minimum Quantity Lubrication (MQL) is now an established alternative to conventional flood cooling in drilling [**Weinert 1999 and Klocke et al. 1996**].

Minimum quantity lubrication also results in a satisfactory tool life for small diameter drills when deep hole drilling, as very recent work has revealed [**Heinemann 2004**]. Current research work is directed towards determining the optimum amount and the most appropriate type of minimum quantity lubricant so that the longest tool life is achieved. However, a vital question that still remains unanswered: is the complete absence of any coolant a viable alternative to MQL without jeopardizing process stability and tool life? With respect to the amount of lubricant supplied, not only is the total amount, in terms of volume per unit of time, of interest but also the manner in which it is supplied.

MQL is of importance because of the limited penetration capability of cutting fluids into a borehole during the drilling process. Once the hole depth exceeds 2–3 times the drill diameter, very little or no cutting fluid can reach the drill tip mainly because the drill and the counter-flow of chips restrict further penetration [**Weinert 1999, Klocke and Gerschwiler 1996]**.

Hence, drilling at a depth exceeding 3 times the hole diameter has to be considered as a near-dry cutting process, even when large amounts of cutting fluid are poured towards the tool. Thus, supplying a cutting fluid throughout a drilling cycle might be considered as a waste of lubricant as no significant advantage in terms of improved lubrication and/or cooling of the drill might be achieved. It merely spoils the process's efficiency. This restricted provision is supposed to be the main reason why MQL very often brings about an advantage in drilling compared to flood cooling.

In contrast to MQL, dry machining has not fully established itself in drilling technology, mainly because of the extremely high thermal load on the drilling tools resulting in accelerated tool wear and unsatisfying overall process stability [**Klocke and Gerschwiler 1996**]. The importance of cooling in drilling was demonstrated by Rehbein [**Rehbein and Bohren 1999**] who was able to prolong the tool life by blending the minimum quantity lubricant with water.

In many cases the decrease in temperature due to a reduction in friction is not sufficient to keep the tool at a tolerable temperature and thus the lubrication is most effective at low cutting speeds, whereas cooling becomes increasingly important at higher cutting speeds. Since drilling is supposed to be a high-speed operation, lubrication cannot occur, because the lubricant cannot penetrate into the tool–work piece interface quickly enough [**Haan et al. 1997**].

According to the U.S. Occupational Safety and Health Administration (**OSHA**) [**Aronson 1995]** and the U.S. National Institute for Occupational Safety and Health (NIOSH) the permissible exposure level (PEL) for metal working fluid aerosol concentration is 5 mg/m^3 and 0.5 mg/m^3 respectively. The oil mist level in U.S. automotive parts manufacturing facilities has been estimated to be 20-90 mg/m^3 with the use of conventional lubrication by flood coolant [**Bennett and Bennett 1985**]. The exposure of such amounts of metal working fluid can cause adverse health effects and safety issues, including toxicity, dermatitis, respiratory disorders and cancer. When considering large system quality, the recirculating coolant in cleanliness and concentration overtime results in variation of tool wear and affects part finish and dimensions. In flood coolant, the trenches and hard piping for a recirculating coolant system hinders the rapid reconfiguration of equipment. In conventional flood coolant, wet chips are produced, that have to be dried before remelting, which incurs cost. But MQL produces dry chips, so the cost of drying chips is reduced [**Filipovic and Stephenson 2006**].

In 2003, a study was conducted in Japan to investigate the Tribological behavior of lubricants for semi-dry application in connection with cutting performance [**Wakabayashi et al. 2003**]. Two kinds of synthetic biodegradable esters and a rapeseed vegetable oil were used. One is a fully synthetic polyol ester the other is a vegetable based synthetic ester. For comparison, neat type cutting oil is used for conventional flood supply. Cemented carbide or Cermet was used as the cutting tool and the work-piece material was JIS (Japan Industrial Standards) S45C carbon steel.

A cutting speed of 200 m/min was used with a feed of 0.1 mm/rev and a depth of cut of 1 mm. MQL was supplied with a pressure of 0.3 MPa and flow rate of 25 ml/h through an external nozzle. The experiments were conducted in a vacuum chamber. When the chamber pressure was 1.0×10^{-4} Pa, a two gas component was introduced into the chamber. After the chamber flow was constant by inlet and outlet gas, machining was carried out. The result indicated cutting performance in MQL machining in ester is superior to that in dry machining. MQL machining with vegetable oil with viscosity of 35.6 mm^2 / s was not preferred. The surface roughness by MQL machining with ester oil was just below 1 Ra, μm as compared to vegetable oil which was 1.25 Ra, μm. The coefficient of friction for ester oil was approximately 1.48 and for vegetable oil 1.52. For tool rake surface analysis, an electron probe microanalysis (EPMA) was done which provided detailed information about surface elements. According to this analysis carbon was significantly observed on the tool face in MQL machining with synthetic ester oil. This analysis implied the possibility of strong absorption of polyol ester on to the tool surface. Such carbon does not exist in MQL using vegetable oil. This lack is probably the reason why the cutting performance of synthetic ester was better than vegetable oil [**Wakabayashi et al. 2003**].

In the initial stages of MQL development low quantities (such as 200 – 300 ml/hr) of lubricants were used in machining Operation [**Machado and Wallbank 1997**]. These low quantities were applied in fast flowing air streams. It was proved that MQL was more efficient when low cutting speeds and high feed rates are used (i.e. cutting speed of 200 m/min and feed rate of 0.15 mm/rev). Cutting and feed force are reduced when machining a medium carbon steel under low cutting speed and high feed rates. The mixture of air-water or air-soluble oil reduces the amplitude of oscillation of the force component. For producing these two mixtures a venturi was designed to mix compressed air with small quantities of a liquid lubricant (water and soluble oil). This venturi ends with a nozzle that directs the mixture onto the rake face of the tool. A pressure regulator and valve were placed between the air compressor and venturi. With the valve shut the air pressure was set to 2.3 bars (34 psi). With the valve fully open the pressure dropped to 2 bars. For water, the mean flow rate was 293.98 ml h-1. For soluble oil, the mean flow rate was 195.76 ml h-1. A P40 uncoated steel cutting grade cemented carbide insert (S6) having SNMG 120404 ISO specification and a CSSNR 3225 M12 tool holder, manufactured by Sandvik were used in all tests. AISI 1040 normalized forged steel bars were used as work materials. The machine tool was a Torshalla S250 CNC lathe with 30 kW of power. Due to the application of mist, an effective exhaust extraction system was required. Cutting and feed force are reduced when a lubricant is applied when machining a medium carbon steel under low cutting speed and high feed rates. Mixtures of air-water or air-soluble oil reduce the amplitude of oscillation of the forced component. The influence of the lubrication is noticeable for low cutting speed and high feed rates, with mixtures of air-water and air-soluble oil outperforming other lubricant conditions tested. The results with air-water combinations were found to be encouraging. This result avoids pollution of the environment and related problems of health and safety, and drastically reduces lubricant costs, although it may cause problems of corrosion. The Experiments of MQL were conducted using diamond-coated and uncoated tools [**Braga et al. 2002**]. The coating improvement of carbide tools and the chemical and mechanical properties of the tool material have caused an increase in tool working life in machining processes. When a diamond coated tool was used, the result was an irregular surface wear of the drill and a decrease in hole quality, compared with the uncoated K10 drill. The experiments were carried out in a rigid CNC machining center with 22 kW of power and maximum rotation of 12,000 rpm. Drills used in the experiments were made of uncoated ISO K10 carbide (NS kind), according to DIN 338 and diamond coated carbide. The K10 carbide drills had an average diameter of 9.986 mm and the diamond drills had an average diameter of 9.992 mm (both with tolerance ISO h8). The work-pieces were made of aluminum–silicon alloy with 7% silicon (SAE 323). The conclusion is the process performance (in terms of forces, tool wear and quality of holes), when using MQL, was similar to that obtained when using a high amount of soluble oil, with both, coated and uncoated K10 drills. These conclusions prove the potential of using this technique in the drilling process for aluminum-silicon alloys. In this experiment two cooling systems were used. The first was a mixture of air and oil (MQL): 10 ml/h of mineral oil was pulverized in an air flow of 72 m^3/h and 4.5 bar of pressure. The second system was a flood of soluble oil (1 part oil to 25 parts water) with a flow rate of 2.4m^3/h. For both systems, the condition and tools, a cutting speed of 300 m/min and feed of 0.1 mm/rev were used. It was observed that the value of flank was similar when using an uncoated K10 drill, (after 612 holes the difference in flank wear was less than 0.050mm). The values of power consumed for the two drill materials, when using MQL were similar at 0.81 and 0.79 Kw for diamond coated and uncoated tools respectively at 20 m feed length. Feed force represented almost the same rate of increase with feed length for all experiments regardless of the cutting condition and tool material. The uncoated K10 drill presented the best results related to the average diameter of the hole. For the diamond coated drill, results are better when MQL was used. For uncoated drills results are similar for both cooling systems [**Braga et al. 2002**].

Hole making had long been recognized as the most prominent machining process, requiring specialized techniques to achieve optimum cutting condition. Drilling can be described as a process where a multi-point tool is used to remove unwanted materials to produce a hole. It broadly covers those methods used for producing cylindrical holes in the work piece. While removal of material in the form of chips new surfaces are cleaved from the work piece accompanied by a large consumption of energy. The mechanical energy necessary for the drilling operation is transformed in to heat leading to conditions of high temperature and severe thermal / frictional conditions at the tool- chip interface [**Ezugwu and Lai 1995**].

The magnitude of the cutting temperature increases though in different degree with the increase of cutting velocity, feed and depth of cut. At such elevated temperature the cutting tools if not enough hot hard may lose their form stability quickly or wear out rapidly resulting in increased cutting force, dimensional inaccuracy of the product and shorter tool life [**Kitagawa et al. 1997**]. This problem increases further with the increase in strength and hardness of the work material.

During drilling process, the most important factor affecting the cutting tool performance and work piece properties is cutting temperature that emerges between drill bit and chip [**Eyup and Babur 2006**]. The cutting temperature directly influences hole characteristics such as diameter, perpendicularity and cylindricity, as well as surface roughness and tool wear [**Eyup and Babur 2006**]. They also investigated the effects of cutting depth, cutting speed, web thickness and helix angle on the temperature. The temperatures associated with the drilling process are particularly important, because drilling is one of the predominant industrial machining processes and heat effects in drilling are generally more severe than in other metal cutting operations. Drills often experience excessive temperatures because the drill is embedded in the work piece and heat generation is localized in a small area. The resulting temperatures can lead to accelerate tool wear and reduce tool life and they can have profound effects on the overall quality of the machined work piece. Drill designers often select the geometrical features of a drill based on the expected temperature profile in the drill point, so accurate prediction of the temperature distribution is imperative [**Matthew and Jun 2006**]. Temperature not only be exaggerated the tool wear but also affect the surface, hole quality and chip formation. The cutting temperature directly influences hole sensitivity, surface roughness, and tool wear [**Eyup and Babur 2006**]. A turning tool typically will not fail due to thermal shock, because it is subjected to this quenching only three or four times per minute when it is withdrawn from the cut at the end of each pass. A face milling operation running at 1000 rpm, on the other hand, subjects every insert to 1000 damaging quenches per minute. Drilling fails somewhere in between with thermal shock occurring every time the drill pulls out of the cut [**Gregory 1999**].

A major portion of the energy is consumed in the formation and removal of chips. The greater the energy consumption, the greater are the temperature and frictional forces at the tool–chip interface and consequently the higher is the tool wear [**Senthil Kumar et al 2002**]. Drill wear not only affects the surface roughness of the hole but also influences the life of the drill bit [**Panda et al. 2006**]. Wear in drill bit is characterized as flank wear, chisel wear, corner wear, crater wear and margin wear [**Panda 2006 and Sanjay 2005]**. Since wear on drill bit dictates the hole quality and tool life of the drill bit [**Panda et al. 2006**].

Worn drills produce poor quality holes and in extreme cases, a broken drill can destroy almost all finished parts. A drill begins to wear as soon as it is placed into operation. As it wears, cutting forces increases, the temperature rises and this accelerates the physical and chemical processes associated with drill wear and therefore drill wears faster [**Sanjay et al. 2005**]. Thrust and torque depend upon drill wear, drill size, feed rate and spindle speed. Researches results show that tool breakage, tool wear and work piece deflection are strongly related to cutting force [**Sanjay et al. 2005**].

The material is removed in the form of chips and evacuated through the drill flutes. It has been demonstrated [**Litvinov 1990, Ackroyd 1998 and Sahu 2003**] that smaller chips are more easily removed from the drill by the action of the flutes, centrifugal forces, and/or metal working fluids. Long chips can become tangled around the drill, can lead to poor hole quality and are more difficult to manage once outside the hole thereby increasing production costs and lowering productivity. Furthermore, while drilling deep holes friction between the drill flutes and chips causes the chips to be evacuated slower than chips are produced. This leads to chip clogging, which in turn causes sudden increase in torque and thrust that may cause drill breakage. Improved chip evacuation will lead to less drill breakage, lower production costs, better hole quality, and increase productivity [**Degenhardt et al. 2005**].

Chips must be small enough to move up the tool's flutes and out of the way. Long, stringy chips can damage surface finish and cause premature tool wear or breakage. Coolant has to get to the tool tip to keep the tool and workpiece cool, as well as force chips out of the hole. A rigid machine tool with good damping characteristics and low spindle run out is required to hit targets for accuracy, repeatability and surface finish. Of course, the right drill geometry will make deep-hole drilling operations much more efficient.

Currently in industries, this high temperature problem is partially tried to be controlled by reducing heat generation and moving heat from the cutting zone through optimum selection of machining parameters and geometry of the cutting tools, proper cutting fluid application and using heat resistant cutting tool materials like carbides, coated carbides and high performance ceramics (CBN, PCBN, PCD etc). The thermal deterioration of the cutting tools can be reduced by using CBN tools [**Narutaki and Yamane 1979**]. If properly manufactured, selected and used, CBN tools provide much less cutting force, temperature and hence less tensile residual stress [**Davies et al. 1996**]. Though CBN tools are extremely heat and wear resistive, those are too expensive and are justified for very special work materials and requirements where other tools are not effective [**Ezugwu and Lai 1995**].

The application of cutting fluid during machining operation reduces cutting zone temperature and increases tool life and acts as lubricant as well [**Beaubien and Cattaneo 1964**]. Also Dhar et al. [**2004**] states that without cooling and lubrication, the chip sticks to the tool and breaks it in a very short cutting time. It reduces cutting zone temperature either by removing heats as coolant or reducing the heat generation as lubricant. In addition it serves a practical function as chip- handling medium [**Cassin and Boothroyed 1965**] But it has been experienced **[Cassin and Boothroyed 1965]** that lubrication is effective at low speeds when it is accomplished by diffusion through the work piece and by forming solid boundary layers from the extreme pressure additives, but at high speeds no sufficient lubrication effect is evident. The ineffectiveness of lubrication of the cutting fluid at high speed machining is attributed to the inability of the cutting fluid to reach the actual cutting zone and particularly at the chip-tool interface due to bulk or plastic contact at high cutting speed. On the other hand, the cooling and lubricating affects of cutting fluid influence each other and diminish with increase in cutting velocity [**Kitagawa et al. 1997**].

Since the cutting fluid does not enter the chip-tool interface during high speed machining, the fluid action is limited to bulk heat removal only.

A large amount of heat is created in dry machining because of rubbing between cutting tool and work piece interface. Dry machining has not fully established itself in drilling technology, mainly because of extremely high thermal load on the drilling tools resulting in accelerated tool wear and unsatisfying overall process stability [**Ezugwu and Lai 1995**]. The optimization of cutting conditions to make them more suitable for dry cutting is done through the increase of feed and decrease of cutting speed. With this, roughly the same amount of heat is generated, but the area of the tool which receives this heat is bigger, making the temperature lower and the amount of chip removed per minute constant (without increasing cutting time). This action may damage the work piece surface finish due to the increase of the feed [**Durval et al. 2002**]. And also in Dry drilling, the drilling tool has to withstand harsh environment conditions, including high temperatures, frictional forces and large mechanical and thermal loads [**Eyup Bagci and Babur, 2006**].

Therefore, it is also necessary to increase the tool nose radius in order to keep the surface roughness at the same level [**Klocke et al. 1997**] so those processes where dry cutting is either not possible or not economical [**Durval et al. 2002**]. The drilling of aluminum–silicon alloys is a process where dry cutting is impossible [**Derflinger et al. 1999**] due to the high ductility of the work piece material.

Minimum quantity lubrication is the same in fashion and small amount of heat is reduced like dry cooling. Usually the high cutting temperature is controlled by profuse cooling [**Sokovic and Mijanovic 2001**]. Sometimes, the costs of tools may increase with the use of minimum lubrication, due to the increase of tool wear [**Durval et al. 2002**]. The MQL system has shown encouraging potentials for precision machining at low feed and high-speed conditions [**Machado 1997**]. Considering the use of the MQL in machining, the vapor, the mist and the smoke of oil can be considered undesirable sub-products, characterizing an increase in pollution by suspension in the air [**Heisel 1998**]. In Germany, the maximum polluter pollution concentration in the air under the mist form is limited in to 5mg/m^3 and for vapor oil the limit is 20 mg/m^3 [**Heisel 1998**]. During machining with MQL only the top most layer of the work piece experiences bulk cooling and air-coolant mixture can't reach to the tool tip due to the hindrance caused by the spiral flute of the drill bit and the counter flow of the chip.

However, such profuse cooling with conventional cutting fluid is not able to solve these problems fully even when employed in the form of jet or mist. With the advent of some modern machining process and harder materials and for demand for precision machining, the control of machining temperature by more effective and efficient cooling has become extremely essential. But in the drilling process, once the hole depth exceeds 2–3 times the drill diameter, very little or no cutting fluid can reach the drill tip mainly because the drill and the counter-flow of chips restrict further penetration [**Weinert et al. 1999** and **Kubota et al. 1999**]. In addition, conventional Cutting fluids, most of the times, are difficult and expensive to recycle, can cause skin and lung diseases to the machine operator and air pollution [**Durval et. al. 2002**].

Flood cooling in the cutting zone can effectively reduce the cutting temperature when machining at lower speed conditions with significant sliding region and where relatively low cutting temperatures are generated. The coolant also acts as a lubricant, thus minimizing friction and lowering component forces and consequently tool life. There is very limited access of the coolant to the tool-workpiece or tool-chip interfaces, which are mainly under seizure condition when machining at high speed conditions. Coolants tend to be vaporized by the high temperature generated close to the tool edge, forming a high temperature blanket that renders their cooling effect ineffective [**Ezugwu 2004**].The film boiling temperatures of conventional cutting fluids is about 350°C [**Ezugwu and Bonney 2003**].

In flood cooling, less and less coolant reaches the tool tip as the deeper the drill penetrates in to the work-piece. Eventually, no coolant can get to the bottom, and machining occur dry. As a result, chips become impacted in the flutes of the tool even though coolant is visibly flowing over the top of the hole. In fact, the hole ends up being dry cut, while the tool heats up and is subjected to premature wear or breakage.

The main problem [**Wertheim and Rotberg 1992**] with conventional coolant is that it does not reach the real cutting area. The extensive heat generated evaporates the coolant before it can reach the cutting area. The high cutting forces generated during machining will induce intensive pressure at the cutting edge between the tool tip and the workpiece. Conventional coolant might not be able to overcome this pressure and flow into the cutting zone to cool the cutting tool. Hence, heat generated during machining is not removed and is one of the main causes of the reduction in tool life. With the use of high-pressure coolant during machining, the tool life and surface finish are found to improve significantly [**Mazukiewicz 1989**, **Lindeke 1991 and Kovacevic 1994**], which is said to be due to the decrease in heat and cutting forces generated. There have been several studies on applying coolant at high pressure at the tool–chip interface, focused on a stationary single cutting edge in a turning operation.

Cryogenic cooling is an efficient way of maintaining the temperature at the cutting interface well below the softening temperature of the cutting tool material. This technology is exploited mainly in the grinding industry because of the high specific energy requirements, which results in high grinding zone temperature which if not properly controlled will lead to surface damage [**Ezugwu 2004**]. Ezugwu [**2004**] found that in cryogenic machining high cutting and thrust forces are generated than in conventional and flood cooling or dry machining applications. This anomaly is attributed to the fact that sub zero temperatures has the consequence of increasing hardness and strength of the work material, hence higher forces are generated with cryogenic cooling [**Hong et al. 2001**]. Tool wear rates when machining titanium alloy Ti-6Al-4V with cemented carbide using Liquid Nitrogen and under conventional cooling at a cutting speed of 132 m min^{-1}, feed rate of 0.2 mm rev^{-1} and a depth of cut of 1.0 mm showed a five fold increase in flank wear for tools subjected to the conventional cooling [**Wang and Rajurkar 2000**]. This type of cooling is effective but not cost effective. Cryogen handling is difficult and it may cause cold diseases if operator wears no safety wear.

High–pressure jet of conventional coolant has been reported to provide some reduction in cutting temperature [**Robert 2004**]. High-pressure coolant can often cut cycle times in half or better and improve surface finish and double or quadruple tool life while delivering a reduction in cycle time [**Frederick Mason 2001**].The idea of delivering coolant under high pressure to the cutting region in order to increase tool life during machining began in early 1950s [**Pigott and Colwel 1952**]. The primary objective of this machining technique is to significantly reduce the temperature generated at the tool-workpiece and tool-chip interfaces when cutting at higher speed conditions. This is achieved by directing coolant under high pressure at the chip-tool interface. This process can also achieve high chip breakability and control through increased chip up curl and compressive stress [**Ezugwu 2004**]. Ezugwu [**2004**] stated that ability to deliver coolant at high pressure very close to the critical point on the secondary shear zone can improve machinability at higher speed conditions. The credibility of this technique of coolant delivery has been thoroughly investigated over the years. The high speed coolant jet traverses the surface faster, thus significantly lowering the film boiling action of the coolant at the cutting area. This consequently minimizes heat transfer to the cutting tool. The high pressure coolant jet creates a hydraulic wedge between the tool and the workpiece, penetrating the interface with a speed exceeding that required even for high speed machining and also alters the chip flow conditions [**Mazurkiewicz 1989**]. The penetration of the high energy jet into the tool-chip interface reduces the temperature gradient and eliminates the seizure effect, offering an adequate lubrication at the tool-chip interface with a significant reduction in friction [**Ezugwu 2004**].

The temperatures generated by the cutting speeds of today's advanced tooling can actually prevent low-pressure flood coolant from entering the cutting zone. The majority of the cooling and lubricating aspects of a flood coolant stream are lost as the coolant is vaporized prior to entering the cutting zone [**Frederick Mason 2001**]. It is the great problem for machining, HPC play well role to minimize this type of problem. Frederick Mason [**2001**] found better solution from it and he states that HPC systems generates high velocity coolant streams moving at several hundred mph. This high-speed coolant easily penetrates the vapor barrier to effectively lubricate and cool the tool. In fact, when machinists apply high-pressure coolant to a longstanding process, which has always produced dark blue chips, they are often amazed that the same or even higher speeds and feeds produce shiny, silver chips that are cool to the touch.

Heat from the drill may also work harden or "heat treat" the workpiece in the vicinity of the hole. Friction from the drill heats the workpiece, and when coolant finally reaches the heated material, the coolant quenches it. On the subsequent peck, the drill encounters the hardened material, causing excessive tool wear or a broken tool and damaged part. The high pressure of the coolant breaks up chips and forces them up the flutes and out of the hole. Cycle times go down, because the pecking process is eliminated while spindle speeds and feed rates can be increased. With higher feed rates, chips tend to form better.

The need for high pressure and high volume coolant in drilling became apparent when gun drills came into use over 100 years ago. The essence of the problem (then and now) with standard low pressure coolant systems is that so much heat is produced that the coolant boils away before it can reach the chip- tool interface where metal is actually cut. The super heated steam forms a barrier that low pressure coolant can't penetrate. Effective cooling does not occur and there is little real lubrication provided. Unfortunately, the vapor barrier that forms is not powerful enough to keep chips from falling back into the chip-tool interface and causing damage. Properly applied high pressure and high volume coolant prevents this vapor barrier from forming by causing a localized pressure increase. So much liquid is forced into the cutting zone that heat is removed and no vapor can form because of the pressurization. When machinists tried high-pressure coolant on standard drilling operations, they found that the benefits of increasing coolant pressure improved the performance of these operations as well. Properly applied high-pressure, high-volume coolant prevents the formation of a vapor barrier by causing a localized pressure increase. This force is liquid into the cutting zone, removing heat, providing lubrication, and flushing chips away from the cut. Damage from heat and chips is eliminated, and tools can cut until they wear out. High-pressure coolant discourages chip welding, prevents the damaging chemical reactions that may occur at high temperatures, and allows drills to last longer [**Gregory 1999**].

Deep hole drilling with a depth of ten times the hole diameter is used in the automobile industry. In the initial development of deep hole drilling using MQL, a depth of 5 times the diameter showed that vibration drilling is effective to a depth of 5 times the diameter [**Hidetaka and Hideyo 1996**]. In this study, drilling a depth of 10 times the diameter was done. A drill of 3mm diameter was used with an overall length of 71mm and point angle of 118°. The cutting condition for both the vibration drilling and conventional drilling were the same. Work material used was SS400. Cutting speed was based on 1700 rev/min. Feed rate was 0.008, 0.16, 0.20 and 0.24 mm/rev. Cutting fluid used was Neat oil type: JIS (2-1). When deep holes were drilled the contact resistance between the chip edges and hole walls increases and produces chip congestion. Increase of feed speed helps to prevent this congestion. Vibration drilling disposes of chips at a fast speed because it accelerates the penetration of oil and produces a large variation of chip thickness. Disposal in vibration drilling extends drill life in comparison with conventional drilling. A study was conducted at Georgia Institute of Technology to compare the mechanical performance of minimum quantity lubrication over completely dry lubrication for the turning of hardened bearing-grade steel materials with low content CBN cutters [**Autret and Liang 2003**]. Process attributes analyzed were surface roughness, cutting temperature, cutting forces, and tool life. A range of feeds from 0.002 to 0.014 inch/rev, cutting speeds of 450 sfpm and depth of cut of 0.012 inch were tested with a triglyceride and propylene glycol ester solution vegetable based cutting fluid at a constant flow rate of 50 ml/hour and a nozzle pressure of 20 psi. The cutting tool used was a low content CBN tool (Kennametal KD5625) with a rake angle of -6° chamfer length of 0.12 mm, horn radius of 0.03 mm, and nose radius of 0.8 mm. A slant bed horizontal lathe (Hardinge T42SP) was used [**Autret and Liang 2003**].

In the context of resulting surface roughness, no noticeable difference was concluded with the use of a near-dry over completely dry condition. However, an improvement of surface finish was felt by near-dry machining under greater depths of cut and feeds such as 0.012 inch and 0.006 in/rev respectively. In the context of a steady-state cutting temperature, a 10% to 30% reduction was consistently observed when a minimum quantity lubrication condition was applied as opposed to completely dry. This result was expected due to an increase in the evaporative heat transfer at the cutting zone. In the contest of cutting forces, there was no significant difference with or without the use of minimum quantity lubrication. The cutting force was approximately 250 N at a feed of 0.012 in/rev. In the context of tool life, the study showed a significant increase from 35% to 50% by minimum quantity lubrication over a wide range of cutting conditions [**Autret and Liang 2003**].

In 2006, a paper published in Machining Science and Technology Journal introduced synthetic polyol esters and described their capacity as a potential MQL fluid, particularly compared with vegetable-based MQL oils, from the viewpoint of optimal secondary performance for MQL operations [**Wakabayashi et al. 2006**].

The studies about cutting fluid application in machining processes have been evaluated that the selection criteria of cutting fluids have been examined. Suitable cutting fluids for various material machining processes have been determined according to cutting tool materials. In drilling operations, a drill rotates while it is fed into a stationary work piece for the production of holes. The interference and relative motion between the drill and the work piece result in a cylindrical hole and material removal in the form of chips. Because of its extensive use, drilling has become an indispensable and important operation in industry which accounts for a large portion of overall machining times and costs.

1.1.1 Machinining with Conventional Twist Drills

In the industries, different the machine accessories and different aircrafts accessories manufacturing purpose, different hard metals are drilled by conventional twist drills and faced with very difficult problem. Different cutting action at the cutting edges of the conventional twist drills used will be presented. The geometry of any type of twist drill has been well recognized to have a very complex geometry as compared to other metal cutting tools.

Obikawa et al. [**2006**] conducted an experiment on 0.45% carbon steel with TiC/TiCN/TiN triple layer coated carbide tool. The comparison was done between a P35 coated cemented carbide tool and a P25 uncoated cemented carbide tool. In the experiment, a P35 tool was used for a 3000 am cutting length and a P25 tool was used for a 1000 m cutting length. Two cutting speeds were used: 4 m/sec and 5 m/sec. The feed rate was 0.12 mm/rev. MQL was applied at the rate of 7 ml/h and the flow rate for the controlled-oil-mist directed grooving tool was set to 2.4 ml/h. The corner edge-wear and flank wear was measured in dry, wet and MQL cooling conditions. Three different air pressures were used: 0.3MPa, 0.5MPa and 0.7MPa. When the cutting speed was 4 m/sec, the feed rate was set to 0.12 mm/rev and the air pressure was set to 0.7MPa. The tool wear (both corner wear and flank wear) were reduced while machining under MQL condition in compare to dry for both the cutting tools. Tool wear was minimum in case of P35 grade cutting tool in compare to P25 grade tool under the same condition. It indicates that the coating on tool also plays a vital role in machining. It can also be observed that at the higher cutting speed of 5 m/sec, the corner wear in dry cutting increased suddenly due to the loss of coating layers. MQL reduced the wear to a large extent even at high cutting speed of 5 m/sec. The results also showed that by increasing the air pressure in MQL from 0.3 MPa to 0.7 MPa, flank wear and corner wear reduced drastically with a constant supply of MQL by 7ml/h.

The application of MQL in turning operation reduces tool wear, surface roughness and cutting temperature at the tool-chip-work piece surface contact as reported by Dhar et al. [**2006**] who conducted an experiment on the turning of AISI 4340 steel. Here, Machining was done with carbide inserts at a cutting speed of 110 m/min, a feed rate of 0.16 mm/rev and a depth of cut of 1.5 mm. The turning operation was done under a dry, wet (flood cooling) and MQL environment. In MQL, the air pressure was set to 7-bar and the flow rate at 60 ml/h. The machining was done for about 45 min. During the experiment, the average principal flank wear, average auxiliary flank wear and surface roughness were measured for different cutting lengths. It was observed that the wear rate and the surface roughness value were lesser in MQL compared to dry and wet cooling conditions. The growth rate of the flank wears decreased in MQL because of the reduction in temperature at the tool-chip interface area near the flank surface of the tool. Reduction in temperature helped to reduce abrasion wear by retaining tool hardness and also helped to reduce abrasion and diffusion types of wear-which are highly sensitive to temperature. The surface finish of the work piece and the dimensional accuracy depend on the auxiliary flank wear.

Basically it consists of three parts, i.e. the shank for mounting the drill into the drilling machine spindle, the body with two helical flutes to provide the required reach to the cutting part and the point which consists of two lips and one chisel edge as formed by the corresponding flanks and flutes. The shank is the portion by which the drill is held and driven. Its function is to transmit the torque and force during a drilling process. Normally, two different types of shanks are used in practice; namely, straight or cylindrical shank and tapered shank. The straight or cylindrical shank is used extensively. It usually has the same diameter as the drill body and the drill diameter ranges from approximately 0.006 to 2 in. The tapered-shank drills have a standard taper (Morse system) and are designed for the conventional twist drills with a relatively larger size ranging from 1/8 to 3.5 in. as recommended in [**Donaldson et al. 1973**].

Generally the shank is made of carbon steel especially for large size drills considering the fact that HSS is much more expensive than carbon steel. For small sized drills, the whole body may be made of HSS. Drill body is the central part of a drill that extends from the shank to the outer corners of the cutting lips at the drill point. The body consists of two helical flutes or grooves to provide the cutting lips when the point is sharpened. It also provides passage for efficient chip disposal and to allow cutting fluid to reach the cutting edges. It should be noted that in the literature, twist drills with three flutes and four flutes have been reported and are generally used when highly accurate holes are required. In order to reduce the friction and interference between the drill and the hole produced, a body clearance is introduced with two narrow margins along the leading edges of the flutes at the drill periphery to support the drill against the hole.

1.1.2 Machinining with Conventional Cutting Fluid

Cutting fluids are used in machine shops to improve the life and function of cutting tools. They are also a key factor in machine shop productivity and production of quality machined parts. Cutting fluid may be applied to a cutting tool/work-piece interface through manual, flood, mist and MQL application. Manual application simply consists of an operator using a container, such as an oil can, to apply cutting fluid to the cutting tool/work-piece. Although this is the easiest and least costly method of fluid application, it has limited use in machining operations and is often hampered by inconsistencies in application. Flood application delivers fluid to the cutting tool/work-piece interface by means of a pipe, hose or nozzle system.

Fluid is directed under pressure to the tool/work-piece interface in a manner that produces maximum results. Pressure, direction and shape of the fluid stream must be regulated in order to achieve optimum performance. Cutting fluids may also be atomized and blown onto the tool/work-piece interface via mist application. This application method requires adequate ventilation to protect the machine tool operator. The pressure and direction of the mist stream are also crucial to the success of the application.

Metalworking fluid used in flood or mist applications is typically stored and distributed utilizing an individual machine tool system or a central reservoir system. Individual machine tools with internal cutting fluid systems consist of a sump for fluid storage, a pump, delivery piping and a spent fluid collection and return system, and a filter to remove contaminants. Coolant re-circulates from the machine sump to the machine tool. Centralized reservoir systems may contain hundreds of gallons of cutting fluid which is distributed to individual machine tools via a pump and piping system. Prior to fluid returning to the central reservoir, it is passed through a filtering system designed to remove contaminants such as metal chips and other particulates.

There are two basic types of MQL delivery systems: external spray and through-tool. The external spray system consists of a coolant tank or reservoir which is connected with tubes fitted with one or more nozzles. To inhibit corrosion, a fluid must prevent metal, moisture and oxygen from coming together.

The primary function of cutting fluid is temperature control through cooling and lubrication. Application of cutting fluid also improves the quality of the work-piece by continually removing metal fines and cuttings from the tool and cutting zone. Chemical metalworking fluids now contain additives which prevent corrosion through formation of invisible, nonporous films. Two types of invisible, nonporous films are produced by metalworking fluids to prevent corrosion from occurring. These include polar and passivating films. Polar films consist of organic compounds (such as amines and fatty acids) which form a protective coating on a metal's surface, blocking chemical reactions. Passivating films are formed by inorganic compounds containing oxygen (such as borates, phosphates and silicates). These compounds react with the metal surface, producing a coating that inhibits corrosion.

The aim of applying cutting fluids during machining is to eliminate, overcome or at least reduce the heat generation effect, friction and corrosion of both the tool and the work-piece [**Nagpal 2004**]. Their resulting positive effects include prompt heat removal, lubrication on the chip-tool interface and chip removal by constantly cleaning the machined zone [**Aluyor et al. 2009**]. Heat is generated and built-up at the region between the tool’s rake and/or flank faces and the work-piece by the action of rubbing together of the tool and work-piece. This may lead to generation of tensile residual stresses and micro cracks at the material surface [**Petterson 2007**]. Frictional energy develops between the duo which leads to rapid tool wear and reduction in tool life.

As cutting fluid is applied during machining operations, it removes heat by carrying it away from the cutting tool/work-piece interface. This cooling effect prevents tools and work-piece from exceeding their critical temperature range beyond which the tool softens and wears rapidly. Fluids also lubricate the cutting tool/work-piece interface, minimizing the amount of heat generated by friction. A fluid's cooling and lubrication properties are critical in decreasing tool wear and extending tool life [**Petterson 2007]**.

Cooling and lubrication are also important in achieving the desired size, finish and shape of the work-piece. No one particular fluid has cooling and lubrication properties suitable for every metalworking application. Straight oils provide the best lubrication but poor cooling capacities. Water, on the other hand, is an effective cooling agent, removing heat 2.5 times more rapidly than oil. Water is a very poor lubricant when used alone and causes rusting. Soluble oils or chemicals that improve lubrication prevent corrosion and provide other essential qualities must be added in order to transform water into a good metalworking fluid [**Petterson 2007**].

The sustainability of the use of cutting fluids and other lubricants can be divided into two aspects [**Salete and Joao 2008]**. The first aspect is about the origin of the resources, which can either be fossil or renewable raw materials, such as mineral oils and vegetable oils, respectively. The other aspect examines the environmental pollution associated with use and discharge of these products.

YG-61 is water soluble cutting fluids developed to be used in the most difficult operations such as Drilling, Milling, Broaching, Cutting and Threading. It provides excellent surface quality after the operation. It also provides very good anti-wear properties and possesses extreme pressure properties, so reduces the coefficient of friction and improves the tool life and tooling cost. It has very good corrosion resistance and minimum mist and foam formation Properties which is chlorine-free. It can be also used for yellow metals (copper, bronze and brass) without changing the color of the material in which it shows excellent performance even under very difficult operation conditions.

Water soluble cutting fluids is suitable for Drilling, Milling, Cutting and grinding of cast steel, alloys steel and all steel Material. It has low volatility, precise composition and Long service life.

1.1.3 Machining with Vegetable Oil based Cutting Fluids

The carbon cycles of mineral oil based products are not closed, but open. This leads to an increase in content of atmospheric carbon dioxide and thus contribute to global warming, an issue of concern to the entire globe. Contrary to mineral based oils, the carbon cycle of products of renewable resources (vegetable oils) is closed. The amount of carbon dioxide liberated during disintegration of organic chemicals equals the amount of carbon dioxide that was originally taken up by the plants from the atmosphere.

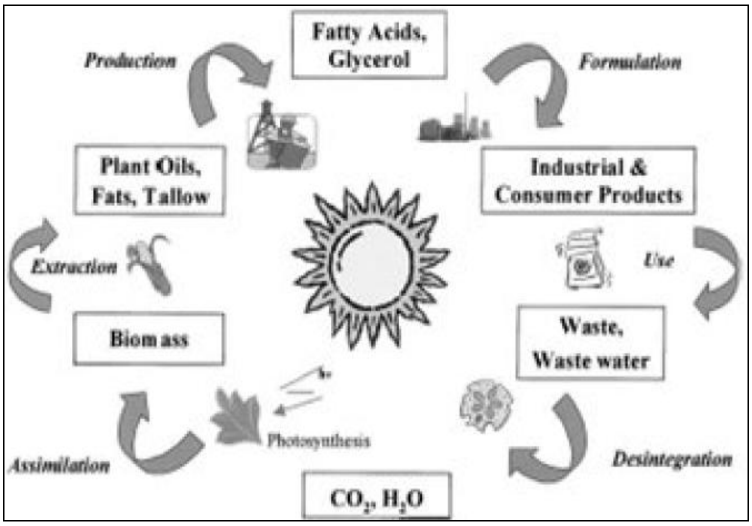


Fig.1.2 The life cycle of renewable resources used in cutting fluids **[Alves and Oliveira**]

Fig.1.2 shows that the activity begins when photosynthesizing plants use up the carbon dioxide found in the atmosphere or dissolved water by the process of assimilation. These plants are then used in production of renewable oils (such as Olive oils) in industries. Such vegetable oils are processed (i.e. formulation) for onward production of drilling fluids which are easily recycled even by disposing into the soil again (disintegration).

Vegetable oils are plant based products, which are reared and refined for specific performance properties and other requirements. Recent studies have shown that bio-based cutting fluids have better lubricities and their viscosities reduce significantly well at high temperature than the mineral oil-based oils. Vegetable oils are being investigated to serve as a possible replacement for non biodegradable mineral oils, which are currently being used as base oil in cutting fluids during machining processes. Vegetable oil-based cutting fluids have reduced overall volume of fluids used for lubrication due to their higher viscosity compared to the mineral oils based fluids. Mineral oils are petroleum based cutting fluids, which are easily obtainable in markets and are relatively excellent lubricants, but their continuous usage in machining will pose environmental contamination and health problems to operators. Table 1.1 and Table 1.2 show the physical properties and features of various cutting fluids. Table 1.3 shows the chemical properties of various cutting fluids.

Table 1.1 Physical properties of various cutting fluids

Cutting Fluids	**Lubrication performance**	**Outstanding anti-rust performance**	**Comprehensive antibacterial properties**	**Strong de-foaming properties**	**Excellent cleaning permeability**
Soluble cutting fluids	Excellent, Effectively reduce the tools wear and get a good work-piece surface quality	Effectively reduce the rust of machine and work-piece	Use for a long time with rare corruption phenomenon	reduce poor cooling lubrication, environmental pollution and increased workload caused by foam problem	make the product's performance of fully play
VG 68 cutting oil	Excellent, Effectively reduce the tools wear and get a better work-piece surface quality	Comparatively low reduce the rust of machine and work-piece	Use for a long time with rare corruption phenomenon	reduce poor cooling lubrication, comparatively low environmental pollution and small effect on workload caused by Foam problem	make the product's performance of fully play
Vegetable oil based cutting fluids	Excellent, Effectively reduce the tools wear and get a better work-piece surface quality	Comparatively low reduce the rust of machine and work-piece	Use for a long time with rare corruption phenomenon	reduce poor cooling lubrication, environmental Friendly and no foam occurred	make the product's performance of fully play

Table 1.2 Features of various cutting fluids

Cutting Fluids	Purity	Environment	Total Acid Number	Metal Working Fluid
Soluble cutting fluids	Dilution Ratio 1:10	Reduced pollution	0.01	Tool life increase
VG 68 cutting oil	high	Eco-friendly	less than 1	Tool life increase drastically
Vegetable oil based cutting fluids	high	Eco-friendly	low	Tool life increase

Table 1.3 Properties of various cutting oil

Cutting Oil	Specific Gravity	Density	Viscosity
Soluble oil	0.917	917 kg/m^3	0.028 Pa.s
VG-68 oil	0.870	870 kg/m^3	0.068 Pa.s
Olive oil	0.918	920 kg/m^3	0.084 Pa.s

1.1.4 Drilling under Dry and MQL Condition

The drilling operations are carried out under dry cutting conditions in which this technique is less effective when higher machining efficiency, better surface finish quality and severe cutting conditions are required. The tool can be isolated from work piece by introducing protective layer on tool face. The cast material in general grey C.I. are particularly well suited for the dry machining due to short chips, low cutting temperature and forces and lubricating effect of the embedded graphite. Problems like chips removal and jamming occur in drilling. The high strength alloy steels AISI 4340 with HRC 32~35 are machined in dry condition by TiN coated HSS-E drill bit but HRC>50 is difficult to machined by un-coated HSS drill bit.

In order to avoid the use of cutting fluids because of their harmful ecological and health effects, machining in many cases is carried out without using any cutting fluid. This is possible only at low cutting speeds and easily machinable materials. Generally, dry machining is not suitable in cases where excellent surface finish and high dimensional stability are required.

This is so because dry machining involves high temperature generation which enhances the formation of built up layer. This built up layer due to its unstable nature breaks and takes away a portion of tool material due to its high adhesive nature causing tool wear. The broken segments when stick to the machined surface deteriorates the surface finish. Thus, dry machining without any lubricating and cooling enhancement is not preferred in general cases of machining.

The drilling operations are carried out with MQL application. There are two basic types of MQL delivery systems: external spray and through-tool. The external spray system consists of a coolant tank or reservoir which is connected with tubes fitted with one or more nozzles.

The external spray system can be assembled near or on the machine and has independently adjustable or to control the fluid flow rate for balancing coolant delivery. It is inexpensive, portable, and suited for almost all machining operations. The advantages of such systems are simplicity and low cost. They are suited to be retrofitted to existing machines with high-pressure, through the tool coolant capability. They are easy to service; no critical parts are located inside the spindle. The amount of lubrication that can be supplied to the cutting zone and consequently affects the performance of the cutting process.

1.1.5 Summary of the Review

In comparison to conventional cutting fluids to minimum quantity lubricants have the advantage of an advanced thermal stability and lubricating capability. Because of this, separation of, firstly, the drill and work piece and, secondly, the drill and chips inside the flutes can be maintained for a longer period of time than is the case with conventional coolants. The most common minimum quantity lubricants today are poly-glycols and ester-oils, which have a good lubrication capability and low evaporation tendency, whereas fatty alcohols exhibit an improved cooling capability due to their high evaporation tendency. However, despite its advanced lubrication capability compared to conventional flood cooling.

1.2 Objectives of the Present Work

The main objective of the present work is to make a experimental investigation on the role of Minimum Quantity Lubricant (MQL) with different cutting fluids (soluble cutting oil, VG68 cutting oil and vegetable oil) in drilling AISI-4340 steel using HSS drill bit and overall benefits in respects of

(i) cooling capacity of the fluid
(ii) dimensional deviation of the hole
(iii) taper of the hole
(iv) surface roughness
(v) tool wear

Chapter-2

Experimental Investigations

2.1 Experimental Procedure and Conditions

Significant progress has been made in dry and semidry machining recently, and minimum quantity lubrication (MQL) machining in particular has been accepted as a successful semidry application because of its environmental friendly characteristics. The aim of the present work is primarily to explore and evaluate the role of such MQL on machinability characteristics of some commonly used tool-work combinations mainly in terms of cutting temperature, chip forms, cutting forces, tool life and product quality, which govern productivity, product quality and overall economy.

Minimum quantity lubrication (MQL) refers to the use of cutting fluids of only a minute amount-typically of a flow rate of 50 to 500 ml/hour-which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition, where, for example, up to 10 liters of fluid can be dispensed per hour. However, the MQL needs to supply at high pressure and impinging at high speed through the nozzle at the cutting zone. Considering the conditions required for the present research work and uninterrupted supply of MQL at constant pressure over a reasonably long cut; a MQL applicator used in the present work is shown in Fig.2.1.

Considering common interest and time constraint, only TiN coated HSS drill bit have been used for the present investigation. Wide scope will remain for further study on MQL effect in drilling steel by TiN coated HSS bit and exotic materials by high performance drill bit. The drilling tests have been carried out by drilling of AISI-4340 steel on a drill machine (Sunlike Machinery RD-750 Radial Drilling Machine, 3.7 KW) by HSS drill bit under both dry and MQL conditions.

Fig.2.1 Photographic view of MQL setup

Drilling ferrous metals by HSS drill bit is a major activity in the machining industries. Drilling of steels involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip-tool contact. Again, the cutting temperature increases further with the increase in strength and hardness of the steels for more specific energy requirement. Keeping these facts in view, the commonly used steel like AISI-4340 steel has been undertaken for the present investigations. The compositions, strength, hardness and industrial use of this steel are given in Table 2.1.

Table 2.1 Characteristics of the used steel [**Rothman 1988**]

Work material	**BHN**	**UTS (Kgf/mm^2)**	**Chemical composition (wt %)**	**Applications**
AISI-4340 steel	275	110	C - 0.360 Mn - 0.920 Ni - 2.850 Cr - 1.410 Mo - 0.520 V - 0.200	➢ Crank shafts ➢ Differential shafts ➢ Heavy duty gears ➢ Turbine discs ➢ High strength studs and bolts

The positioning of the nozzle tip with respect to the HSS drill has been settled after a number of trials. The photographic view of the experimental set-up is shown in Fig.2.2 and the conditions under which the machining tests have been carried out are briefly given in Table 2.2.

Fig.2.2 Photographic view of the experimental set-up

Table-2.2 Experimental conditions

Machine tool	: Sunlike Machinery RD-750 Radial Drilling Machine
Work material	: AISI-4340 steel (228 mm x 102 mm x 16.40 mm)
Cutting tool	: TiN coated HSS (Φ=8 mm)
Process parameters	
Cutting velocity, Vc	: 11.435 m/min
Feed rate, So	: 0.09 mm/rev
Depth of cut, t	: 16.00 mm
Flow rate	: 100 ml/hr
Environment	: ➢ Dry ➢ MQL with soluble oil ➢ MQL with VG 68 cutting oil ➢ MQL with olive oil

The cooling capacity of the cutting oil (soluble oil, VG 68 cutting oil and olive oil) used in this experiment is important has been measured using a Muffle furnace. The maximum temperature measured in the middle of the work piece was 400°C, obtained after keeping it inside the furnace for a period of 7.0 minutes. After heating, the work pieces were submitted to cooling condition similar to the experiments. The temperature was measured by a K-type (Cromel-Alumel) thermocouple for about 7.0 minutes. This thermo-sensor was connected to the work piece through a hole that allowed it to reach the center of the work piece. The cutting fluid was injected at a distance of 15 mm from the upper part of the work piece. The cooling capacity of the different cutting fluids is shown in Fig. 2.3. From Fig.2.3, it is evident that the cooling capacity of VG68 cutting oil is more in compare to other cutting fluids.

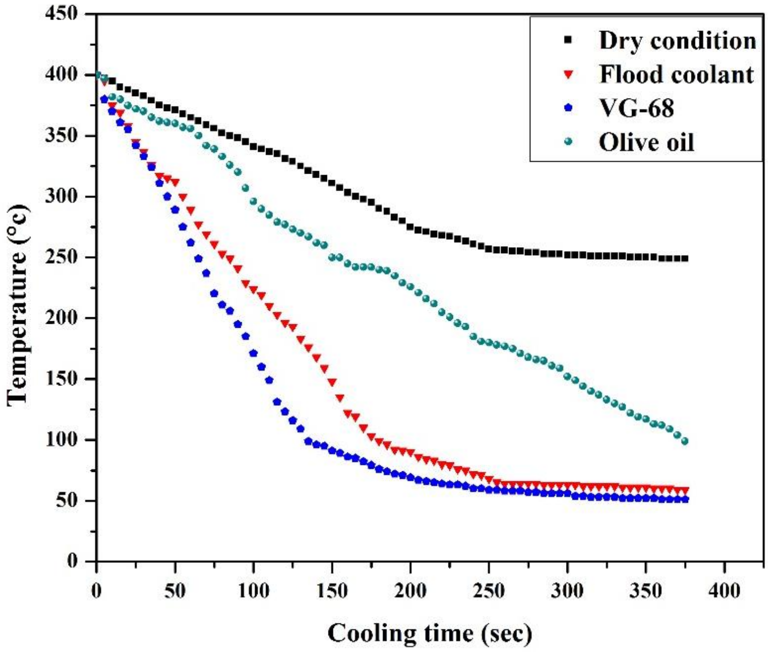


Fig. 2.3 Cooling capacity of the air and cutting fluids used in the experiments

2.2 Experimental Results

2.2.1 Number of Hole

The specimen was shaped by turning and facing in traditional lathe machine. Both surfaces were finished by using surface grinding machine; Punching has been done on the top surface of the specimen in right way in order to locate the drill bit at right place. Punching was done on the specimen maintaining equal distance in between centres. The work-piece was placed on the table of the drill machine and clamped very rigidly. A hollow cylinder was placed keeping the work piece at its centre, whose sole purpose was to control chips and coolant flow. Drill bit was placed on the top surface of the located work-piece and holes were drilled sequentially (like 1, 2, 3, 4…….) under dry and MQL condition.The photographic view of the holes is shown in Fig.2.4.

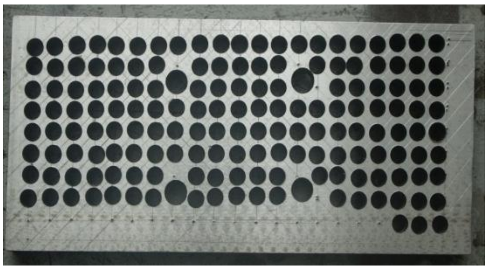
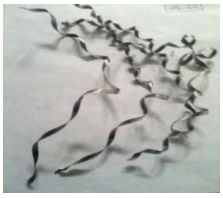


Fig. 2.4 Photographic view of number of holes under both dry and MQL conditions

2.2.2 Chip Formation

Chips were collected after the completion of every drilling operation. Drilled chips were allowed for some time to become clean from coolant and cool down. Collected chips were washed out with acetone, dried and preserved in a desicator packing with aluminum foil. The photographic views of chip are shown in Table 2.3.

Table 2.3 Shape and colour of chip of AISI 4340 Steel under dry and MQL conditions

Cutting speed (m/min)	Feed rate (mm/rev)	Environment			
		Dry	MQL		
			Soluble oil	VG 68 cutting oil	Olive oil
11.47	0.09				

2.2.3 Roundness Deviation

The deviation in diameter and roundness of the holes were measured by a precision digital slide caliper having least count 0.01 mm. At least 16 measurements with same alignment were taken for each hole. Digital slide caliper was turned to anti-clock wise direction while measuring the roundness. Table 2.2 shows the average, maximum and minimum diameters measured in the first third part of the hole length under both dry and MQL conditions with different cutting fluids. It can be seen in the table that the standard deviation of average diameter obtained under MQL conditions is lower than that obtained using dry condition, which means that the MQL presented a better quality. Fig.2.5 and Fig.2.6 show the roundness of the holes close to the entrance and end of the holes obtained during drilling the steel under dry and MQL with different cutting fluids.

Table 2.4 Diameter close to the entrance and end of the hole

Environment	Diameter close to entrance of the hole				Diameter close to the end of the hole			
	$D_{maximum}$ (mm)	$D_{minimum}$ (mm)	$D_{average}$ (mm)	Standard deviation	$D_{maximum}$ (mm)	$D_{minimum}$ (mm)	$D_{average}$ (mm)	Standard deviation
Dry	8.085	8.0625	8.072188	0.006915	7.985	7.915	7.929938	0.015354
MQL (Soluble oil)	7.965	7.955	7.961563	0.00395	7.9425	7.9275	7.934	0.005599
MQL (VG 68 oil)	8.0075	7.9875	7.994125	0.005018	7.9575	7.925	7.934563	0.007159
MQL (Olive oil)	8.0275	7.9775	7.99375	0.016708	7.955	7.9425	7.9495	0.003634

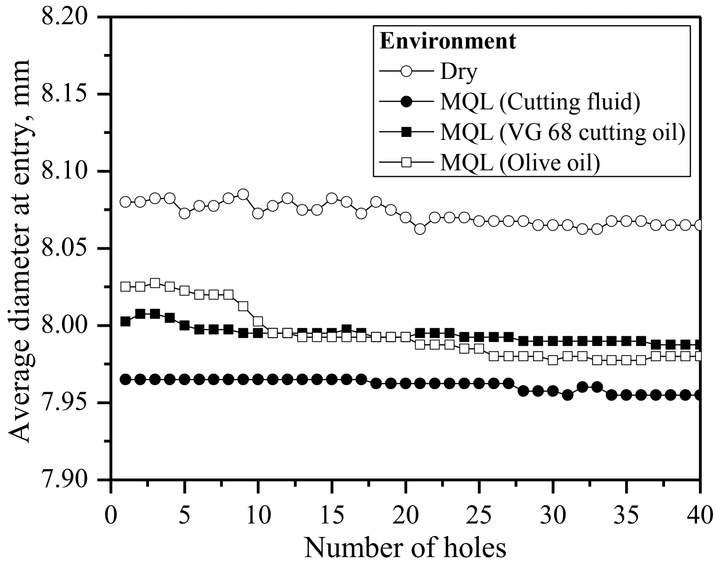


Fig. 2.5 Variation of average diameter at entry of the hole during drilling AISI 4340 steel by TiN coated HSS drill bit under different environments

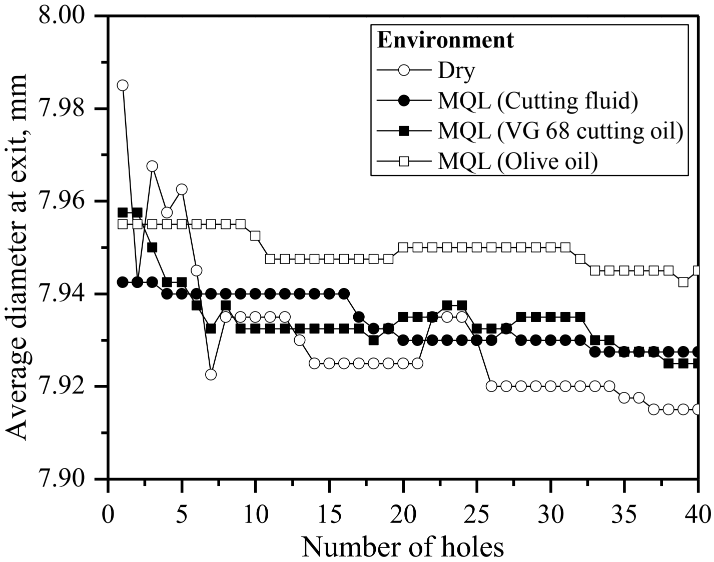


Fig. 2.6 Variation of average diameter at exit of the hole during drilling AISI 4340 steel by TiN coated HSS drill bit under different environments

2.2.4 Diameter Deviation or Taper

Fig.2.7 and Fig.2.8 show the taperness and diameter deviation under dry and MQL with different cutting fluids condition. The average taper values and their dispersion were smaller under MQL condition. Moreover, in both conditions the average taper values were positive, i.e., the diameters in the entrance of the holes were bigger than at the end. These bad results found for the holes made under dry condition are due lack of lubrication action, which made the diameter in the beginning of the holes to increase.

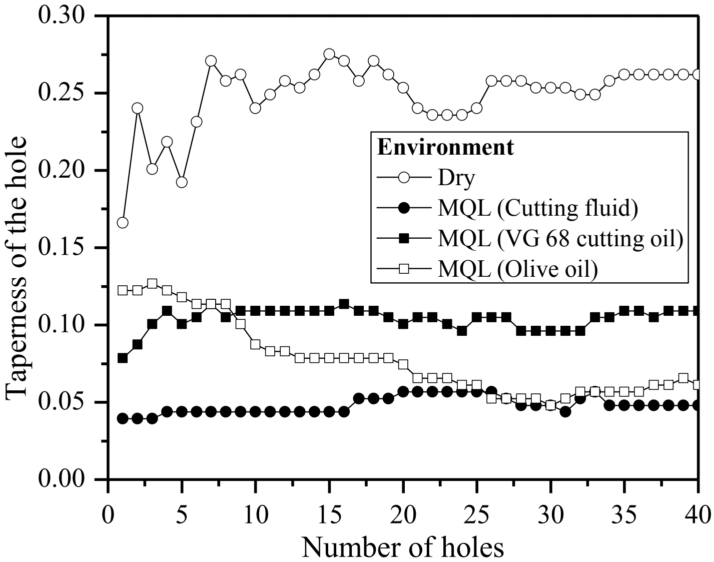


Fig. 2.7 Variation of taperness of the hole during drilling AISI 4340 steel by TiN coated HSS drill bit under different environments

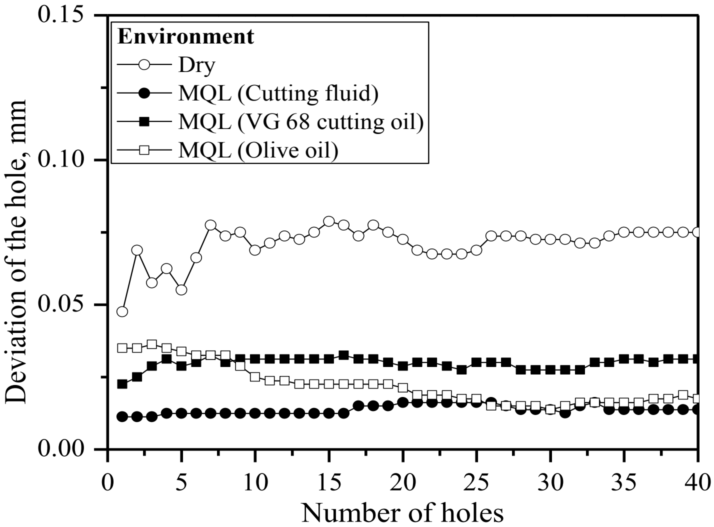


Fig. 2.8 Variation of deviation of the hole during drilling AISI 4340 steel by TiN coated HSS drill bit under different environments

2.2.5 Surface Roughness

The variations of surface roughness for various machining conditions at constant feed rate, spindle speed are shown below in Fig.2.9. The surface roughness values decreases with the consecutive changes of cutting conditions. It is clearly shown that for all cutting conditions, the surface roughness values obtained using MQL with olive is less than other machining conditions. This is due to low viscosity with better lubricating effects between work-piece and tool interface. It facilitates to reduce build-up-edge formation. The surface finish is good for using olive oil MQL fluid application with compared to soluble oil and VG-68 MQL application fluid.

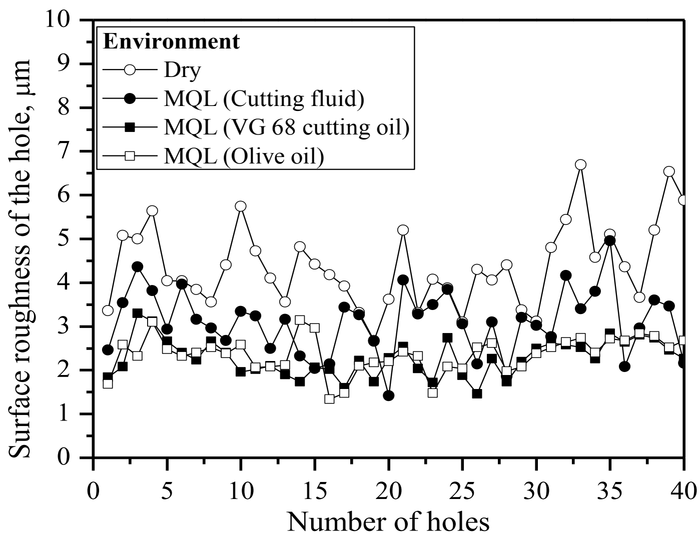


Fig. 2.9 Variation of surface roughness of the hole during drilling AISI 4340 steel by TiN coated HSS drill bit under different environments

2.2.6 Tool Wear

The individual four tools are used for four different machining conditions one dry and three types of MQL fluids applications. Every machining condition there are 40 holes drilled and then flank wear were measured by the metallurgical microscope [Carl Zeiss]. The tool flank wears for dry and MQL with soluble oil, VG-68 cutting oil and olive oil are found 32 µm, 30 µm, 26 µm and 14 µm respectively. Fig. 2.10 shows the growth of flank after drilling 40 holes under dry and MQL with different cutting fluids.

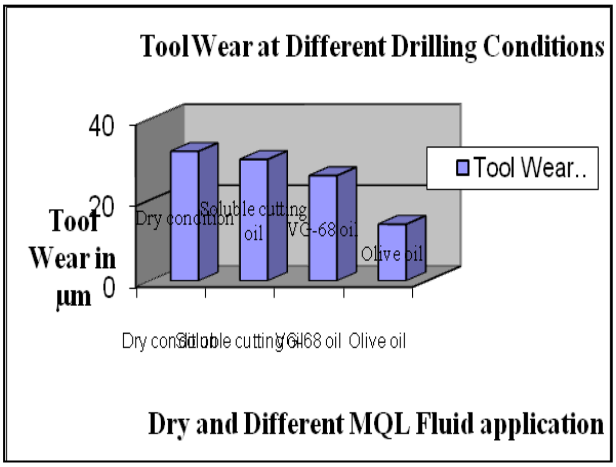


Fig. 2.10 Effect of Tool wear at dry and different cutting fluid application

Chapter-3

Discussion on Experimental Results

3.1 Number of Hole

Number of hole in drilling operation is a major concern. Small number of holes drilled by one bit increases the manufacturing cost due to tooling cost and cost for replacement of the tool. Maximum possible numbers of drilled holes with a single piece of bit are the prime necessity for high production manufacturing. During drilling huge amount of heat is produced due to shearing of metal, friction between chips and flute and rubbing the flank with newly cleaved surface. Machining with higher speed flank of drill bit wears out, drill bit tip burns and melts by higher temperature produced in the cutting zone. Dhar et al. 2004 found that in dry condition, for AISI-1060 steel, after completing 10 holes carbide drill bit was too worn out to do further operations impossible. For this wearing tendency due to lot of heat sometimes drill bit break down within a short time.

AISI-4340 steel was drilled under dry and MQL with different cutting fluids condition by 8 mm HSS drill bit is shown in Fig. 2.4. In dry condition drill bit becomes burnt blue in color after completing 40 holes on AISI-4340 steel and creates very rough surface with changed roundness. Very small chips are found on the surface of the hole as wielded matter due to accumulation of huge heat while cutting. On the other hand in MQL with different cutting fluids condition drill bit remains its original color and without any burning holes metallic color chips are shown in Table 2.1. Holes dimension are very close to acceptable limit having proper shape and no wielded chip is found in the MQL drill.

3.2 Chip Formation

The chip formations are investigated to drill AISI 4340 steel using titanium nitride coated drill bit under dry and MQL with different cutting fluids conditions with a spindle speed of 455 rpm and feed rate of 0.09 mm/rev. The surface roughness of a drilled surface depends on the nature of chip removal from the cutting zone. The chip formation examination would give a clear view of the machining parameter influencing the tool wear and surface roughness. During the drilling process, chips were collected and examined for general characteristics. On observing the nature of chip formation, chips are short and no curls material is formed. This makes the chips disposal easier from the machined surface; the hard AISI 4340 alloy steel particles and soft graphite particles act as regions of crack propagation, and hence act as effective chip breakers.

In this study, the performances of olive oil, mineral oil-based cutting fluid and soluble oil were compared with dry condition during machining AISI 4340 steel. The chip formation rates of the work-piece using olive oil as vegetable oils as cutting fluids under cutting speed (455 rev / min) and feed rate (0.09 mm/rev) were compared with that of mineral oil VG-68, soluble oil and dry machining. The average chip thickness of dry machining conditions is 0.39175 mm, where the average chip thickness of conventional oil (i.e. soluble oil) is 0.33825 mm which is less than that of dry machining. Olive oil gives the overall lowest chip thickness of 0.20075 mm due to its better lubricating property with low viscosity. This is followed by that of the VG-68 oil and the conventional oil (i.e. soluble oil) as compared with dry machining of mm thickness. Fine surface morphology indicates improved surface roughness compared to using other cutting fluids. Based on these results, Olive oil is being recommended as viable alternative lubricants to the mineral oil during machining AISI 4340 steel.

3.3 Roundness Deviation

Before the analysis of the quality parameters of the holes, it is important to note that neither diameter nor any other quality parameter of the hole was influenced by tool wear. It can be seen in Table 2.4 that the standard deviation of the average diameter obtained under MQL condition is lower than that obtained using dry condition, which means that the MQL presented a batter quality with presence of proper lubrication at the chip-tool interface.

Fig.2.5 shows the roundness of the holes close to the entrance and Fig. 2.5 shows the roundness of the holes close to the end of AISI-4340 steel. This result can be attributed to the lower cutting force and the shorter diameters. In dry condition due to excessive heating, scarcity of coolant and lubricant, rubbing the tool face with work material and commencement of tool wear, the deviation is very large. Fig.2.5 shows the roundness of the holes close to the entrance and Fig. 2.6 shows the roundness of the holes close to the end of the holes obtained during drilling AISI-4340 steel and it can be seen from these figures show that the roundness deviation has a little change from the beginning to the end of the holes under MQL application with compare to dry condition, this result can be attributed to the lower cutting force and smaller roundness deviation due to effective lubrication. The roundness deviation is not uniform and steady in AISI-4340 steel as shown in Fig. 2.5 and Fig. 2.6, because of high hardness due to high alloying elements. The roundness deviation was smaller at both the entrance and end of the holes under HPC condition in compare to dry condition for both the steel, because of high lubricant capacity.

3.4 Diameter Deviation or Taper

From the above Fig.2.7 shows the diameter deviation under dry and MQL with different cutting fluid conditions. The diameter deviations of holes using MQL (Cutting fluids i.e. soluble oil) are low with compare to dry and other two types of cutting fluids application and the diameter deviations of holes using MQL (Cutting fluids i.e. olive oil) are low compare to dry and VG-68 cutting fluids application. This is also followed by that of the VG-68 cutting oil as compared with dry machining condition. Thus, the diameter deviation values would become smaller under MQL condition with compare to dry machining condition.

From the above Fig. 2.7, The Taperness of hole of the work-piece using Olive oil as vegetable oils based cutting fluids under cutting speed (455 rev / min) and feed rate (0.09 mm/rev) were compared with that of mineral oil VG-68, soluble oil and dry machining. In drilling operation at MQL (cutting oil i.e. soluble oil) environment, the taperness of holes are low with compare to dry and other different cutting fluids application. This is also followed by that of the VG-68 oil and the olive oil as compared with dry machining condition. The Results are shown that the drilling operations at dry machining environment, the taperness of holes are found high with compare to different cutting fluids application. Thus the Soluble oil gives the overall lowest taperness of holes.

3.5 Surface Roughness

The variations of surface roughness values for various machining conditions at constant feed rate, spindle speed are shown in Fig. 2.9. From Fig. 2.9, the surface roughness values decreases with the consecutive changes of cutting conditions. It is clearly shown that for all the cutting conditions, the surface roughness values obtained using Olive oil as vegetable oil based MQL application fluid is less than other dry, soluble oil and VG-68 MQL fluid applications. This is due to low viscosity with better lubricating effects between work-piece and tool interface. It facilitates to reduce build-up-edge formation. The surface finish is good for using olive oil MQL fluid application with compared to soluble oil and VG-68 MQL application fluid. Hence, usage of olive oil is advantageous in applications that require good surface finish.

3.6 Tool wear

The individual four tools are used for four different Machining conditions one dry and three types of MQL fluids applications. Every Machining conditions there are 40 holes drilled and then Flank wears are measured by the metallurgical Microscope. The tool flank wears for dry and MQL with soluble oil, VG-68 cutting oil and olive oil are found 32 µm, 30 µm, 26 µm and 14 µm respectively. Fig. 2.10 shows the growth of flank after drilling 40 holes under dry and MQL with different cutting fluids. The Results are shown that the drilling operation at dry machining environment, tool wears is high compare to different cutting fluids application. Drilling operation at MQL (using olive oil) environment, tool wears is low compare to dry and other different cutting fluids application.

Conclusions

The main objectives of the present investigation are to compare the performance of drilling AISI 4340 steel by TiN coated twist drill bit in terms of number of holes, chip formation, roundness deviation, diameter deviation or taper and surface roughness by under different cutting conditions (dry and MQL with different cutting fluids). The effect MQL with different cutting fluids on flank wear of drill bit has also been presented in this study.

- The number of hole drilled under MQL with different cutting fluids condition is much higher in compared to dry condition. But the number of hole drilled is more when drill under MQL with olive oil in compare to other cutting fluids. It indicates that the MQL with olive oil is more effective than other cutting fluids.

- The chips thickness formed using MQL with olive oil as cutting fluid was lowest, probably due to its better lubricating ability. This allows easier and deeper penetration of cutting tool into work piece and better metal removal rate.

- Due to excessive heating, scarcity of coolant and lubricant, rubbing the tool face with work material and commencement of tool wear, in dry condition the roundness deviation is very large where the roundness deviation is very low while drilling under MQL with different cutting fluids. But the roundness deviations are found very low while drilling under MQL with using soluble oil.

- The diameter deviation values would become smaller under MQL condition with compare to dry machining condition.

- The surface roughness in machining with olive oil sample gave competitive result of finest and smoothest view as compared with mineral oil-based VG-68 oil, soluble oil sample and dry condition machining, which is an indication of good surface roughness. Better surface finish shows that there is lesser friction and wear between tool and work-piece

- The flank wear under dry and MQL with soluble oil, VG-68 cutting oil and olive oil are found 32 µm, 30 µm, 26 µm and 14 µm respectively. The tool wears is found to be low while drilling under MQL with olive oil compare to dry and other different cutting fluids application.

References

Ackroyd, B., Compton, W.D. and Chandrasekhar, S., “*Reducing the need for cutting fluids in drilling by means of modulation-assisted drilling*”, Proc. of the International Mechanical Engineering Congress and Exposition, Vol. 8, pp. 405–411, 1998

Attanasio, A., Gelfi, M., Giardini, C. and Remino, C., “*Minimum quantity lubrication in turning wear*”, Vol. 260, pp. 333-338, 2006

Autret, R. and Liang, Y., “*Minimum Quantity Lubrication in Finish Hard Turning*”, Master’s Thesis, Georgia Institute of Technology, Atlanta, Georgia, USA. 2003

Baradie, M.A.E., “*Cutting Fluids, Part II: Recycling and clean machining*”, Journal of Materials Processing Technology, Vol. 56 pp. 798-806, 1996

Baradie, M.A.E., “*Cutting Fluids, Part I: Characterisation*”, Journal of Materials Processing Technology, Vol. 56 pp. 786-797, 1996

Barrow, G., “*Wear of cutting tools*”, Tribology-1, pp. 22–30, 1972

Bartz, W.J., “*Ecological and environmental aspects of cutting fluids*”, Lubrication Engineering, Vol. 57, pp. 13-16, 2001

Beaubien, S.J. and Cattaneo A.G., “*A study of the Role of Cutting Fluid in Machining Operating*”, Lubrication Engineering, Vol. 10, pp. 74-79, 1964

Boelkins, C.U., “*Cutting Tool Engineering*”, Vol. 3, pp. 71-75, 2009

Bono, M. and Jun, N.,"*The Location of the Maximum Temperature on the Cutting Edges of a Drill*", International Journal of Machine Tools and Manufacture, Vol. 46, pp. 901-907, 2006

Boubekri, N. and Shaikh, V., "*Machining Using Minimum Quantity Lubrication*", A Technology for Sustainability, International Journal of Applied Science and Technology Vol. 2, No. 1, 2012

Braga, D.U., Diniz, A.E., Miranda, G.W.A. and Coppini, N.L., "*Using a Minimum Quantity of Lubricant and a Diamond Coated Tool in the Drilling of Aluminum-Silicon Alloys*", Journal of Materials Processing and Technology, Vol. 122, pp. 127-138, 2002

Briant, C.L., Banerji, S.K. "*Tempered martensite embrittlement in phosphorus doped steels*", Metal. Trans., Vol. 10A, 1729–1739, 1979

Brinksmeier, E., Walter, A., Janssen, R. and Diersen, P., "*Aspects of cooling lubrication reduction in machining advanced materials*", Proceedings of the Institution of Mechanical Engineers, Journal of Engineering Manufacture, pp. 769-778, 1999.

Callister, W.D., "*An Introduction to Material Science and Engineering*", 3rd edition, Wiley, New York, 1994

Carlson, M.F., Narasimha, B.V. and Thomas, G., "*The effect of austenitizing temperature upon the microstructure and mechanical properties of experimental Fe:Cr:C steel*", Metall. Trans. Vol. 10A, pp. 1273–1281, 1989

Cassin, C. and Boothroyed, G.,"*Lubrication Action of Cutting Fluid*", Journal of Mechanical Engineering Science, Vol. 7, pp. 67-81, 1965.

Chai, M.F. and Laird, C.,"*Mechanisms of cyclic softening and cyclic creep in low carbon steel*", Mater. Sci. Eng. Vol. 93, pp. 159–174, 1987

Davies, M. A., Chou, Y. and Evans, C. J., "*On Chip Morphology, Tool Wear and Cutting Mechanics Hardened Steels*", Annals of CIRP, Vol. 45/1, pp. 77-82, 1996

DeGarmo, E.P., Black, J.T., Kosher, R.A., "*Materials and Processes in Manufacturing*", Maxwell MacMillan Publication, 7th Edition, New York, USA, pp. 578-581, 1984

Derflinger, V., Bra¨ndle, H. and Zimmermann, H., "*New hard/lubricant coating for dry machining*", *Surface Coating Technology*, Vol. 113, pp. 286–292, 1999

Dhar, N. R , Rahman K. M , Islam, S. and Hossain, M., "*Using a minimum quantity of lubricant (MQL) and a carbide tool in the drilling of AISI-1060 steel*", Journal of Mechanical Engineering, IEB, Vol. ME 33, pp. 22- 31, 2004

Dhar, N. R., et al. "*An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel*", International Journal of Machine tools and Manufacture, Vol. 47, pp. 748-753, 2007.

Dhar, N. R., et al. "*Effect of minimum quantity lubrication (MQL) on tool wear and surface roughness in turning AISI-4340 steel*", Journal of Materials Processing Technology, Vol. 172, pp. 299-304, 2006

Dhar, N. R., et al. "*The influence of minimum quantity lubrication (MQL) on cutting temperature, chip and dimensional accuracy in turning AISI-1040 steel*", Journal of Materials Processing Technology, Vol. 171, pp. 93-99, 2006.

Donaldson, C., Le Cain, G.H. and Gould, V.C., "*Tool design*", McGraw Hill, New York, 1973

Durval, U.B., Anselmo, E.D., Gilberto, W.A.M. and Nivaldo L.C., "*Using a minimum quantity of lubricant (MQL) and a diamond Coated tool in the drilling of aluminum–silicon alloys*", Journal of Materials Processing Technology, Vol. 122, pp. 127–138, 2002

Eyup, B. and Babur O., "*Investigation of the effect of drilling conditions on the twist drill temperature during step-by-step and continuous dry drilling*", Materials and Design, vol. 27; pp. 446–454, 2006

Eyup, B. and Babur, O., "*Finite element and experimental investigation of temperature changes on a twist drill in sequential dry drilling*", International Journal Advance Manufacturing Technology, Vol. 28, pp. 680–687, 2006

Ezugwu, E.O. and Lai C.J., "*Failure Modes and Wear Mechanisms of M35 High Speed Steel Drills when Machining Inconel 901*", Journal of Mat. Processing Tech., Vol. 49, pp. 295-312, 1995

Ezugwu, E.O. and Bonney, J. "*Effect of High-pressure Coolant Supplies when Machining Nickel-base Inconel 718, Alloy with Ceramic Tools*", STLE, 2003

Ezugwu, E.O. and Lai, C.J., "*Failure Modes and Wear Mechanisms of M35 High Speed Steel Drills when Machining Inconel 901*", Journal of materials Processing Technology, Vol. 49, pp. 295-312, 1995

Ezugwu, E.O.,"*High speed machining of aero-engine alloys*", Journal of the Brazil Society of Mechanical Science and Engineering. Vol. 26, No. 1/11, 2004

Klocke, F. and Eisennbla¨tter, G., "*Dry Cutting*", Annals of the CIRP Vol. 46/2, pp. 519-526, 1997.

Filipovic, A. and Stephenson, D.A., "*Minimum Quantity Lubrication (MQL) Applications in Automotive Power-Train Machining*", Machining Science and Technology, Vol. 10, pp. 3-22, 2006

Frederick, M. "*Benefits of high-pressure coolant*", Machine Shop Guide Web Archive, 2001

Galloway, D.F., "*Some experiments on the influence of various factors on drill performance*", Trans. A.S.M.E., Vol. 79, pp. 191-231, 1957

Glenn, T.F. and Antwerpen, F.V., "*Opportunities and market trends in metalworking fluids*", Lubrication Engineering, Vol. 54, pp. 31-37, 1998

Gregory, S.A., "*The pressure's on to improve Drilling*", Vol. 51, No. 1, 1999

Haan, D.M., Batzer, S.A., Olson, W.W. and Sutherland, J.W., "*An experimental study of cutting fluid effects in drilling*", Journal of Materials Processing Technology, Vol.71 pp. 305–313, 1997

Heinemann, R., "*Improving the Performance of Small Diameter Twist Drills in Deep-Hole Drilling*", PhD-Thesis, UMIST, 2004

Heisel, U. and Lutz, M., "*Pesquisa de fluido de refrigeração e de lubrificação, Máquinas e Metais*", Vol. 388, pp. 40-49, 1998

Hidetaka, K., and Hideyo, T., "*Drilling of a Small and Deep Hole Using a Twist Drill*", The Japan Society of Mechanical Engineers, Vol. 62, pp. 3691-3697, 1996

Hong, S.Y., Ding, Y. and Jeong, W., "*Friction and cutting forces in cryogenic machining of Ti-6Al-4V*", International Journal of Machine Tools and Manufacture, Vol. 41, pp. 2271-2285, 2001

Horn, R.M. and Ritchi, R.O., "*Mechanisms of tempered martensite embrittlement in low alloy steel*", Metal. Trans. Vol. 9/A, pp. 1039–1047, 1978

Huang, D.H. and Thomas, G., "*Structure and mechanical properties of tempered martensite and lower bainite in Fe-Ni-Mn-C steels*", Metal. Trans. Vol. 2A, pp. 1587–1596, 1971

Irvine, K.J., "*The development of high-strength steels*", J. Iron Steel Inst. Vol. 12 pp. 620–629, 1962

Jeff, A.D., Richard, E.D. and Shiv, G. K., "*Generalized Groove-type Chip Breaker Effects on Drilling for Different Drill Diameters and Flute Shapes*", International Journal of Machine Tools and Manufacture, Vol. 45, pp.1588–1597, 2005

Kang, D.C., "*Geometry analysis and CAD/CAM Software for twist drills*", Ph.D. Thesis, The University of Melbourne, 1997

Kitagawa T., Kubo, A. and Maekawa, K., "*Temperature and Wear of Cutting Tools in High Speed Machining of Inconel 718 and T_i-6V-2S_n*", Wear, Vol. 202, pp. 142-148 1997

Kubota, H. and Tabei, H., "*Drilling of a small and deep hole using a twist drill, Transactions of the Japan Society of Mechanical Engineers*", Part C, 62/601, pp. 3691–3697, 1999

Kwon, H., Cha, J.C., Kim, C.H., "*The effect of grain size on fracture behavior in tempered martensite embrittlement for AISI 4340 steel*", Mater. Sci. Eng. Vol. 10, pp. 121–128, 1988

Machado, A.R. and Wallbank, J., "*The Effect of Extremely Low Lubricant Volumes in Machining Wear*", Vol. 210, pp. 76-82, 1997

MaClure, T.F., Adams, R., Gugger, M.D. and Gressel, M.G., "*Comparison of Flood vs. Microlubrication on Machining Performance*", 2007

Obikawaa, T., et al., "*High-speed grooving with applying MQL*", International Journal of Machine Tools and Manufacturer, Vol. 46, pp. 1854-1861, 2006

Popke, H., Emmer, Th. and Steffenhagen J., "*Environmentally clean metal cutting process-Machining on the way to dry machining*", Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, pp. 329-332, 1999

Quaile, R., et al., "*Understanding MQL Machining with minimum quantity lubricant can save money and improve both tool life and part finish*", Modern Machine Shop, 2011

Sahu, S.K., et al. "*Effect of groove-type chip breakers on twist drill performance*", International Journal of Machine Tools and Manufacture, Vol. 43, pp. 617–627, 2003

Salete, M.A., et al., "*Vegetable based cutting fluid- An environmental alternative to grinding process*". Proceedings at 15th CIRP International Conference on Life Cycle Engineering, Brazil, 2008

Shaw, M.C., "*Metal Cutting Principles*", Clarendon Press, Oxford, England, pp. 292-332, 1991

Shimizu, K. and Nishiyama, Z., "*Electron microscopic studies of martensitic transformation in iron alloys and steels*", Metal. Trans, Vol. 3A, pp. 1055–1066, 1972

Silva, M.B.D., and Wallbank, J., "*Lubrication and application method in machining, Lubrication and Tribology*", Vol. 50, pp. 149-152, 1998

Sokovic, M. and Mijanovic, K., "*Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes*", Journal of Materials Processing Technology, Vol. 109, pp. 181-189, 2001

Sreejith, P.S., and Ngoi, B.K.A., "*Dry machining; Machining of the future*", Journal of Materials Processing Technology, Vol. 101, pp. 287-291, 2000

Strenkowski, J.S., Hsieh, C.C. and Shih, A.J., "*An analytical finite element technique for predicting thrust force and torque in drilling*", International Journal of Machine Tools and Manufacture, Vol. 44, , pp. 1413-1421, 2004

Tejasmaru, B.E. "*Effects of minimum quantity lubrication (MQL) on tool life in drilling AISI 1018 steel*". Master of Science (Engineering Systems-Mechanical Systems), pp. 73, 2012

Tous, J. and Ferguson, L., "*Mediterranean fruits*", pp. 416-430, 1996

Wakabayashi, T., Inasaki, I., Suda, S., and Yokota, H., "*Tribologial Characteristics and Cutting Performance of Lubricant Esters for Semi-Dry Machining*". CIRP Annals, Vol. 51 No.1, pp. 61–64, 2003

Wakabayashi,T., Inasaki, I. and Suda, S., "*Tribological Action and Optimal Performance Research Activities Regarding MQL Machining Fluids*", Machining Science and Technology, Vol. 10, pp. 59-85, 2003