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Analysis Of Near Dry Machining Using Minimum Quantity Lubrication-A Technical Review.

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Abstract :
Cutting fluid is a vital element in a machining processes and is used to remove heat and reduce friction thereby enhancing a number of important economic as well as quality parameters like cutting tool life and surface finish. However it also has an impact on manufacturing cost, ecological damages and occupational health problems and these coupled with global trend of low cost and high productivity hinder the use of wet machining processes. Near dry machining as a substitute for flood cooling is an eco-friendly process that uses minimum amount of cutting fluid and with OoW-concept it is becoming more effective. The understanding of effectiveness mechanism of near dry machining based on Rebinder Effect is important to analyze and understand both qualitative and quantitative aspects of process parameters in machining.
***Keywords* - Cutting Fluid, Minimum Quantity Lubrication, Aerosol, Oil on Water, Rebinder Effect**

I. INTRODUCTION:

Cutting fluids(CF) have been extensively used in various machining operations for multiple purposes. The expected primary functions of CF are cooling(heat removal) and lubrication (friction reduction) as well as to reduce the severity of the contact processes at cutting tool-chip and cutting tool-work piece interfaces[1,2,3].The secondary functions include washing of machined parts, chip transportation (as in deep hole drilling where CF transports the chip to considerable distance),corrosion protection and controlling of machining dust[1,4].Several advantages are to be gained by applying CF that include; an increase in tool life, easier handling of work piece, reduction in the thermal distortion of work piece, and better surface finish[5]. The advantages caused by the cutting fluids are covered up due to its negative effects on environment and operator"s health [1,2,5].CF often consist of complex chemical mixtures with upto 25 components such as base oil stocks, emulsifier, corrosion inhibitors, extreme pressure agents and biocides[6].The machine tool operator exposed to CF has risk of inhalation , ingestion of small fluid droplets(aerosols) and skin exposer, leading to variety of diseases from dermatitis to cancer[**7**]. It has been found that oil mist levels in the U.S. automotive parts manufacturing facilities when traditional flood coolant application is used is of the order of 20 to 90 mg/m3 while recommended permissible exposure level for metalworking fluids by OSHA [Occupational Safety and Health Administration-USA] is 5mg/m3.NIOSH [TheNational Institute of Occupational Safety and Health] recommendation is 0.5 mg/m3[5].

In the current competitive manufacturing era, end users mainly focus on reduction in cost and improvement in productivity. CF incurs a significant part of the manufacturing cost[1].CF accounts for upto 15% of a shop production cost[8].One leading European automotive plant is reported the cost of CF as high as 17% of total manufacturing cost,and tool cost upto 8%.[1,8].This high cost of CF is due to strict environmental and regulatory burdens[6]. Manufacture, use and disposal of CF from ecological and health aspects become very important due to environmental regulations[1].The cost of purchasing and disposing CF per year in USA is 48 billion dollars, 71billion yen in Japan,and one billion marks in Germany[9,10,11].The cost of maintaining and eventually disposing CF combined with the health and safety concerns, have led to a heightened interest in either eliminating CF altogether or limiting the amount of CF applied in machining processes[1,6].The former process is known as Dry Machining(DM) while later is known as Near Dry Machining(NDM)or Minimum Quantity Lubrication(MQL)[5].

To cut the cost associated with CF, dry machining is the best alternative. Despite the advantages of dry machining such as cleaner parts, no waste generation, reduced cost of chip recycling etc. The big obstacle to shift to dry machining is the big capital investment required. The machines and tools designed for conventional CF cannot be used directly for dry machining[12].The high temperature generated in dry cutting not only creates problem for work piece handling but also affects metallurgical properties of surface being machined and residual machining stresses[1].More thermal loads on tool and work piece may also result in increased levels of tool wear[5]. Hence NDM is one of the best solution to alleviate negative impacts of CF. NDM not only is cost effective but also improves the machined surface integrity characteristics. These facts stress on the need to further understand the whole process[13].

1. Near Dry Machining :

NDM is a machining method that delivers the required minimum quantity lubricant mixed with air and performs machining through continuous supply of this oil/air mixture to the tool tip. A typical flow rate of 50 to 500 ml/hour is used in NDM which is about three to four orders of magnitude lower than the amount commonly used in flood cooling conditions[14]. In near dry machining, the cutting fluids used are usually synthetic esters(chemically modified vegetable oils) and fatty alcohols. These high performing cutting fluids have excellent lubrication and natural dissolving properties. Furthermore they are environmentally friendly[5,15]. In NDM, a very small amount of lubricant is directly sprayed on the cutting area. The mixture of air and oil (CF)in the form of aerosol(mist) is used in NDM[1,5].Aerosols means gaseous suspension(hanging) into air of liquid or solid particles For NDM aerosols are oil droplets dispersed in a jet of air. Atomization process is used for generation of aerosols. Atomization involves conversion of bulk liquid into spray or mist form most often obtained by passing the liquid through nozzle[16].Apparatus in which atomization process is carried out is called as atomizer(refer Fig-1).The design and functioning of atomizer is a critical factor for NDM ,as concentration of aerosol and droplet size depend on it.

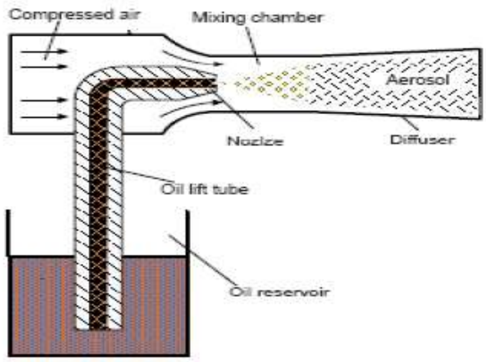

Figure:1 Model of Atomizer

In NDM:Type I -external aerosol supply;for mixing of oil(CF) and air there are two ways available[17,18]. First mixing air and oil inside the nozzle,In this oil and compressed air are supplied to the ejector nozzle and the aerosol is formed just outside the nozzle(refer Fig-2). Second is, oil and air is mixed outside the nozzle. This type of systems are less costly and needs simple changes(retrofitting) in existing machine tools. The cutting tools used in conventional flooding system can be used. The location of nozzle with respect to cutting tool is static in this. This type of NDM is difficult to use for operations like drilling, boring.

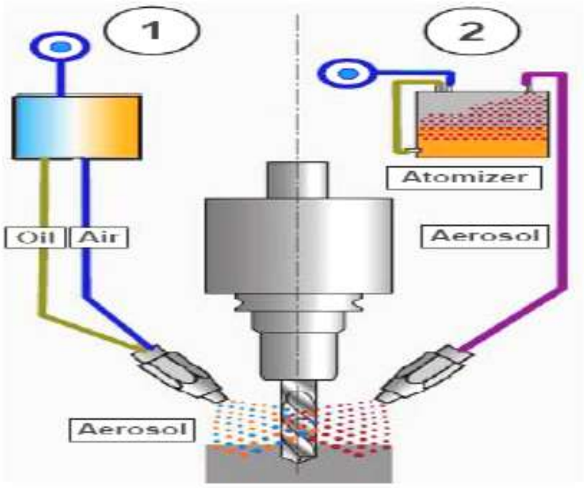

Figure:2 NDM:Type- I

In NDM:Type II-internal aerosol supply(through tool),the aerosol is supplied through the cutting tool similar to the high pressure method of internal CF supply. The atomization process can be carried out externally or internally i.e. inside the spindle of machine tool[18].This type of systems are easy for installation. More accuracy to control aerosol parameters is an advantageous feature of this type.

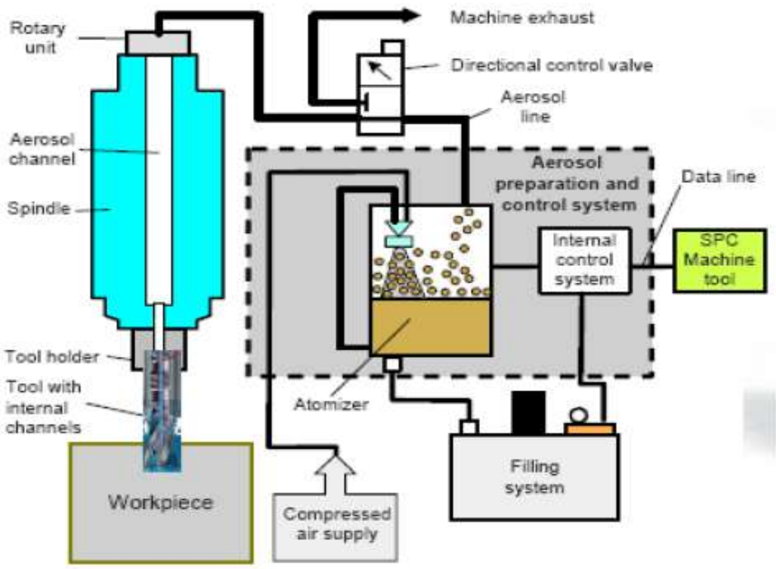

Figure:3- NDM:Type II-internal aerosol supply(through tool),external atomization [18]

2. Oil film-On-Water NDM:

In NDM, the lubrication function is achieved to a great extent by directly spraying the oil to machining zone. The cooling and flushing functions can be obtained by blowing the air. The cooling is limited compared to flood supply. Heat transferred by air convection is limited. Cooling is mainly achieved by vaporization of the cutting fluid, as vaporization absorbs a lot of heat which decreases the temperature of tool and work piece. To enhance cooling along with lubrication, Oil film on Water droplet(OoW)concept is developed(refer Fig-4)[19,20].The water and oil droplets flow with pressurized air from nozzle to cutting zone. Water vaporizes immediately after it touches the tool-chip interface and this chills the contacted surfaces. Then the oil(lubricant) at cutting zone reduces the friction between tool and chips. Pressurized air can cools down the surface and blows away the chips. The cooling is achieved due to high specific heat capacity, density and thermal conductivity of water compared with air and lubrication is achieved due to specific configuration of droplet[18,19].When droplet reaches the hot surface (tool/work piece), the oil(lubricant) spreads over the surface in advance of water spreading. The water droplet is expected to carry the lubricant, spreading the lubricant effectively over the hot surface, and cooling the surface [18,19].To implement this concept practically specially designed discharge nozzle is required.

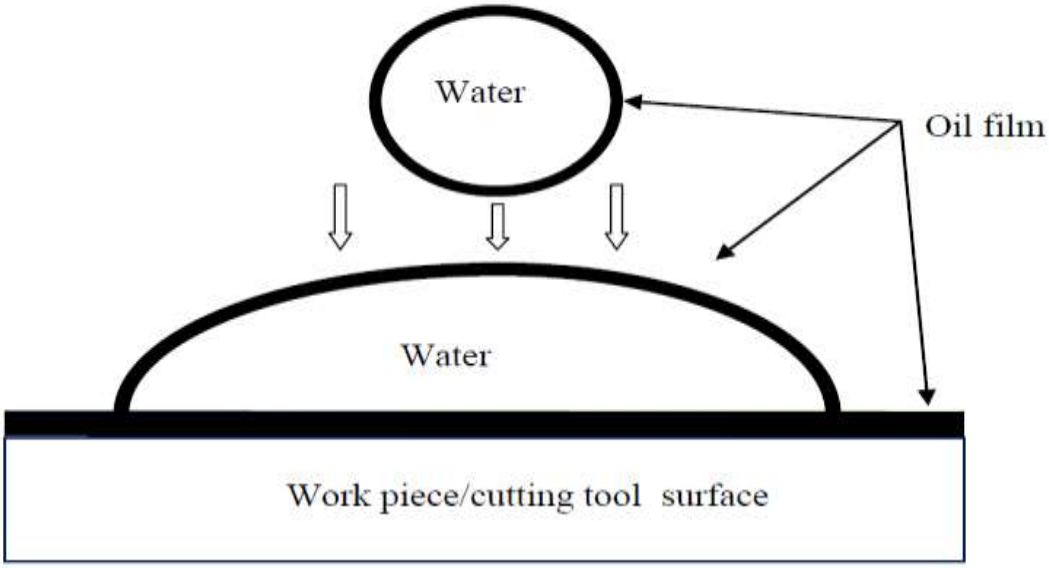

Figure:4 OoW(Oil On Water) Concept

3. Some Reported Results of NDM :

NDM has been applied to both open-faced and closed-face machining operations. Yokota [21] has reported that MQL system is considerably effective in terms of tool wear, finished surface roughness in end milling, turning and tapping operations compared to dry machining. Ueda et al[18] found that the temperature reduction in turning using oil-mist is approximately 5%,while in oil-mist end milling it is 10-15% and in oil mist drilling it is 20-25% compared to the temperatures in dry cutting. Dhar and Khan[22]found that NDM with use of vegetable based oil reduces the cutting forces by about 5-15%.In comparison with wet machining Dhar et al[23] for turning of 4340steel using NDM. They found that the temperature at the tool-chip interface is reduced by 5-10% and the tool life and finish of the machined surfaced enhanced by 15-20%.Matsuoka et al[21]applied MQL to hobbing process with uncoated and coated tool. They found that for uncoated tool there is marked decrease in flank wear and for coated tool crater wear is smaller compared to dry cutting,The finished surface roughness obtained with MQL is smaller compared to dry machining for uncoated and coated tools. Autret and Liang[24]studied the effect of NDM in finish hard turning of hardened high carbon steel using low content CBN tools .They reported 10 to 30 % reduction in cutting temperature compared to dry machining and significant increase in tool life-over 30%.Lio and Lin[25] applied NDM in high speed milling of hardened steel to compare it with dry cutting. They concluded that the tool life can be enhanced by NDM as compared to dry cutting .NDM provides extra oxygen to tool-chip interface so as to promote the formation of protective oxide layer. Systematic classification and analysis of reported results for NDM is difficult due to lack of complete information on the experimental conditions including the parameters of the aerosols[18].CF type and its flow rate, the nozzle design, the distance between nozzle and tool tip, are important parameters affecting performance of NDM[26]. Unfortunately, most of these important parameters are not reported in many of the research and studies on NDM[18].

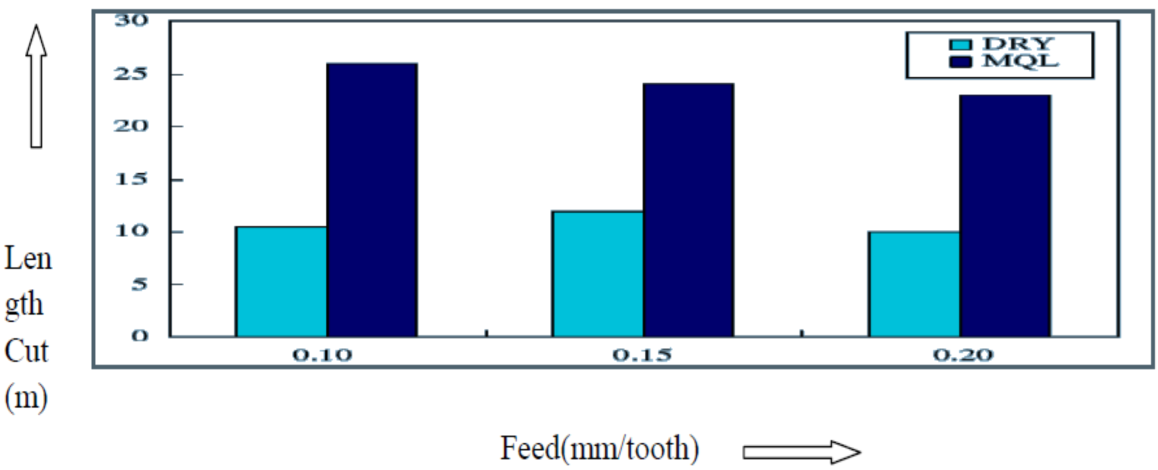

Figure:5 Tool life as a function of feed rate and cutting environment cutting speed ,V=300m/min ,depth of cut of 0.3mm. (Operation: High speed milling, Work piece Material: Hardened steel)[25]

4. Rebinder Effect –Mechanism for Effectiveness of NDM:

Explanations to clarify the effectiveness mechanism of NDM compared to wet and dry machining is scarcely reported in the literature [18].The known explanations are based on oil mist principle that was developed by a bearing manufacturer in Europe during 1930s[18].Boundary lubricating layer of EP additives and accurate delivery of the lubricant to the contact surface just before they engage into a contact plush cooling by oil droplets evaporation is used to explain effectiveness of NDM. Very high specific pressure occurs at the interfaces in metal cutting[1].Hence explanation based on penetration of tool-work piece interface by oil due to high pressure of compressed air[18] needs reality checks. Embrittlement action of CF reduces the strain at fracture of the work material. This action is based on the Rebinder effect[1,16,18].

The results of Rebinder"s study showed that absorbed films of CF prevents micro cracks from closing. Each microcrack in the machining zone serves as a stress concentrator, results in lower energy required for cutting. Embrittlement action of CF based on Rebinder effect is one of the feasible explanation for effectiveness of NDM[18].The only feasible way for NDM to work in metal machining is to enhance the embrittlement of the layer being removed and thus to reduce the work of plastic deformation[18,21].NDM uses oil in atomized form which possesses great ability to enhance Rebinder effect[18]. Rebinder effect is „alternation of the mechanical and physical properties of materials due to the influence of various physiochemical processes on the surface energy"[1]. Adsorption, chemisorptions, surface electrical polarization and surface chemical reactions can be used to lower the surface energy of a solid to change its mechanical properties. Therefore the research to understand the effectiveness of NDM should be driven in this direction[1,18,26].

V. Conclusion:

Considering the economical, ecological and occupational health aspects of cutting fluids in machining, Near Dry Machining or Minimum Quantity Lubrication is an alternative solution to minimize its negative impact. There is a greater need to understand the mechanism of effectiveness of Near Dry Machining as well as the effect of parameters like nozzle design, flow rate of cutting fluid. The Rebinder effect may open up the possibility to understand near dry machining process with environment friendly cutting fluids and research efforts have to be directed towards achieving the same in different machining scenarios.

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