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Conceptual review on Effects of Application of Nano Particle Inclusion on Tool Wear During Machining of Difficult to Cut Materials

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Abstract:*Nanofluids are fluids engineered by dispersing nanometer size particle in a base fluid in colloidal state. The paper discussed the findings on application of nano particle inclusion in conventional cutting fluid during machining of difficult to cut materials. It is reported in literature that, nanofluids have a much higher and strongly temperature – dependent thermal conductivity at very low particles concentration than conventional fluids. Also nanofluids have excellent tribological properties. Aerospace materials are generally considered to be difficult to machine owing to several inherent properties of the materials. For example, Titanium is a poor conductor of heat. Therefore, high cutting temperatures are generated when machining titanium alloys and the fact that the high temperatures act close to the cutting edge of the tool is the principal reason for the rapid tool wear. One of the approaches to address this issue is use of highly thermal conductive fluid, which can dissipate heat rapidly from cutting zone. It would therefore be of interest to explore the use of nanofluid as cutting fluid during machining operation of very hard metals. It is observed from various studies that co-efficient of chip tool interface can be significantly reduced by nanofluid in emulsion of metal cutting fluid.*

Keywords: *Tool Wear, Nanofluid, Cutting fluid, Difficult to cut materials, Wet machining.*

1. INTRODUCTION

Cutting fluids are used in metal cutting operation for improving tool life, reducing work piece thermal deformation, lubricating the cutting process primarily at low cutting speeds, cooling the work piece primarily at high cutting speeds, improving surface finish, flushing away chips from the cutting zone and corrosion protection of the machined surface. Nanofluid is a new class of fluids engineered by dispersing nanometer size particles into base fluid such as water, ethylene glycol, engine oil, cutting fluids etc. Research has shown that the thermal conductivity and the convection heat transfer coefficient of the base fluid can be significantly enhanced by the suspended nanoparticles [1]. Moreover tribological research showed that lubricating oils with nanoparticle additives such as MoS_2, CuO, TiO_2, Diamond, etc. exhibit improved load-carrying capacity, anti-wear and friction reduction properties respectively. [1]-[2] The improved heat transfer, wetting and tribological properties of these nanofluids can provide better cooling and lubrication in the minimum quantity lubrication cooling as well as flood cooling during the machining process.

2. LITERATURE REVIEW

Literature revealed that nanofluids with enhanced thermal and tribological properties reduce the cutting forces and the temperature during the grinding process and hence improve the tool life.

During rough cutting operation at low speed friction is predominant and cutting fluid must have good lubrication property compared to thermal diffusivity. Y. Y. Wu (2007) has noted in his research as shown in figure 1, that lubrication oil with inclusion of TiO2 and CuO nano particles have lesser coefficient of friction compared to diamond nano particles and lubrication oil. Moreover CuO, added to standard oils exhibit good friction reduction and anti wear properties.

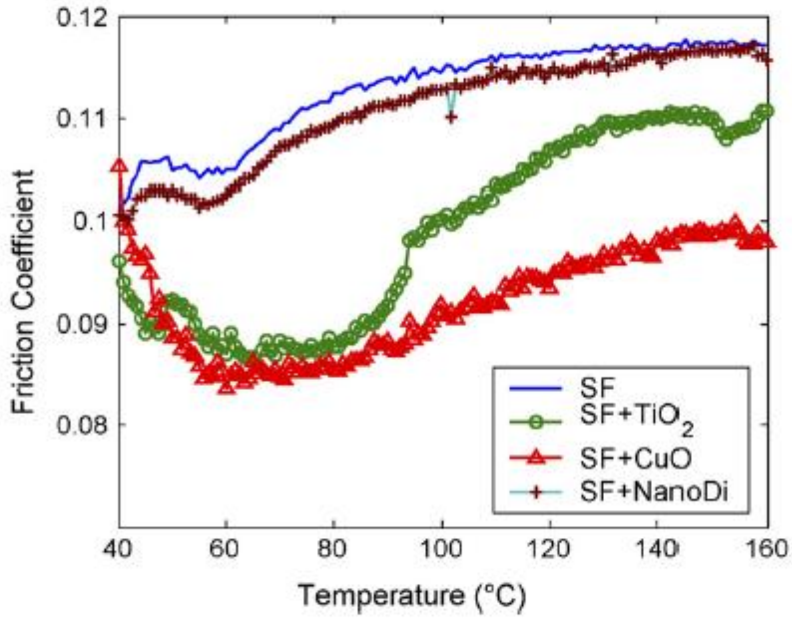

Figure 1 Friction coefficient of SF oil with and without nano particles [15]
(SF – lubrication oil with SAE viscosity no. - SAE30 (LB51153))

Shen et al. (2008) conducted experiments on grinding using MoS_2 nano particles based nano fluid and noted that nano particles of MoS_2 could provide key value addition in MQL grinding. Also, author reported that the nanoparticles of MoS_2 offer unique advantages in MQL as they navigate in the grinding zone, thus affecting reduction of grinding forces up to 27% and increase of life of expensive grinding wheels by increasing the G-ratio up to 46%. [1]

Srikant et al. (2009) noted in their experimentation with CuO nano particles based nano fluid that the tool tip temperature reduced significantly during application of nanofluid. Moreover they concluded that in nanofluid with nano particle concentration ≤ 1%, the decrease in temperatures is more drastic compared to concentrations greater than 1 percent. [3]

Parash et al. (2010) have successfully studied the role of nano lubricants in MQL grinding process through friction and wear analysis at the grinding grit and the work piece interface. They reported that sliding friction analysis at different speed conditions showed a notable reduction in the co-efficient of friction values when soybean oil was used for MQL with nano lubricant additive. This reduction was consistent with the reduction in tangential grinding forces. [4]

Lee et al. (2010) carried out nanofluid MQL meso-scale grinding process using nano diamond particles. They concluded that the normal and tangential components of the grinding forces in the case of nanofluid grinding process were reduced by 33.2% and 30.3% respectively when compared with the case of dry air grinding. [5]

S. Khandekar et. al. (2012) has found that adding 1% Al_2O_3 nanoparticles to the conventional cutting fluid greatly enhances its wettability characteristics compared to pure water and conventional cutting fluid. The great reduction of crater and flank wear is attributed to enhanced thermal properties, improvement in wettability, and lubricating characteristics of the nano-cutting fluid. [6]

M. Amrita et. al. (2014) has concluded in his study that dynamic viscosity of nanocutting fluid was found to increase with increase in concentration of nanographite, which may increase its lubricity. Moreover Nano cutting fluids applied as MQCL showed better machining performance compared to MQCL application with conventional cutting fluid, flood lubrication, and dry machining. [7]

Anuj Kumar et. al. (2015) has reviewed that the nano-enriched cutting fluid exhibits better tribological properties compared to its base fluid. Also, the inclusion of nanoparticles in cutting fluids showed a remarkable reduction in power consumption, specific energy, cutting force, surface roughness, nodal temperature, torque in drilling, tool wear and friction coefficient during machining. [8]

Y. Shokoohi et. al. (2016) has observed better heat transfer rate during machining. They conclude that utilizing nanofluids as coolant and lubricant lead to lower tool temperature, tool wear, higher surface quality and less environmental dangers. [9]

From the literature review it may be summarized that nano particles provide superior lubrication between surfaces under extreme loading condition during machining process. Therefore it may not be out of place to presume that increased thermal conductivity of nanofluid and effective flow of nanofluid between the tool and work piece can also provide better results in turning process as well. With this reasoning, conceptual study has been carried out to check tool wear during machining of difficult to cut materials. Additionally, hard metals, like Ti-6Al-4V maintained high strength at elevated temperature and its low modulus of elasticity further impairs its machinability. [11]-[13] One of the approaches to address this issue is use of highly thermal conductive fluid, which can dissipate heat rapidly from cutting zone. So, its time to explore nanofluid as cutting fluid during machining of aerospace and very hard materials.

3. SELECTION CRITERION FOR NANO FLUID IN MACHINING OPERATION

Economy of machining is influenced by cutting fluid consumption, recycling and disposal of waste fluid. Cutting fluid carries on an average 16-20 percent of total cost of machining. Various factors' like, machining process, work piece material, cutting tool material, process parameters, cost of cutting fluid, surface finish, environmental effect and occupational health hazard derive the selection of cutting fluid. Lubrication and cooling requirement during machining process can be determined by the type of machining process, method of applying cutting fluid (flood, mist, manual, high pressure), rigidity of the system, work piece material and its hardness and microstructure, cutting tool material, geometry and coating and process parameters i.e. speed, feed, and depth of cut. [13]

In general cutting fluids employed during machining process are water and water miscible- straight oils, soluble oils, semi synthetic fluids and synthetic fluids. It is well known that no one type of fluid can provide best lubrication and cooling qualities simultaneously for any machining process. Lubrication and cooling effects are adversed, if we increase one effect by changing the composition of cutting fluid the other will decrease. Nano fluid can balance these two effects to a certain extent. Water is the best coolant whereas oil is the best lubricant. So, nanofluid must be formulated in a way that it can optimize cutting requirements i.e. cooling and lubrication as well as non cutting requirements like corrosion inhibition, favorable fluid residues, nonflammability, filterability, nontoxicity, disposability and recyclability.

Nano fluid can be formed with 1% to 5% oleic acid layered (surfactant) nano particles in water (base fluid) or water soluble oil (secondary fluid) with additives such as Chlorine, Sulphur and Phosphorus. Nano fluid does the cooling while the conventional additives with nano particle provide the lubrication and corrosion inhibitions. [13]

In heat transfer analysis, thermal diffusivity (α) is the thermal conductivity divided by the volumetric heat capacity. Cutting fluid with high thermal diffusivity rapidly absorbs the heat from the cutting zone and reduces the tool tip temperature. So, higher thermal diffusivity of the cutting fluid is desirable. As calculated by S. Doshi et. al. in his paper that thermal diffusivity of CuO, TiO2 and Al2O3 is 308.642 cm2/s, 201.044 cm2/s and 106.316 cm2/s respectively. [13]

Literature review suggests that copper (Cu), gold (Ag) and silver (Au) have the highest thermal conductivity enhancement. But nano particles of pure metal are having tendency of forming oxides and are also very costly. Whereas oxides of pure metal like CuO and Al_2O_3 are more suitable for nanofluid. Diamond nano particle exhibits better tribological property, it is not feasible to deploy as cutting fluid because of high cost and difficult manufacturability. Both oxides, CuO and Al_2O_3 looks more promising as they are economical and technically feasible for forming nano fluid.

In general, experimentally available data shows that nano particle size affects the thermal conductivity of basefluid. As the nano particle diameter is reduced, the effective thermal conductivity of nano fluids become larger. Nowadays nano particles are available in plenty of varieties in shape and size; shapes, like spherical, square, tube, multi wall tube, rod, cylinder etc… and in size from 30 nm to 110 nm. The tribological and thermal properties of the nano particles predominantly vary with the shape. Experimental investigation suggests that spherical and multi wall tube particles exhibit both lubrication and thermal properties better, for the application as cutting fluid.

Also, concentration of the nano particle affects the behavior of nano fluid. The effective thermal conductivity of nanofluid increases with the volume fraction of nanoparticles. However, as the volume fraction is increased, the assumption that nanoparticles are suspended in base fluid becomes invalid. Therefore, the new thermal phenomenon of nanofluid is only observed in a low volume fraction range. [14]

4. NEED FOR DEVELOPMENT OF NANO FLUID RECIRCULATION SYSTEM

Thermophysical properties of nanofluid largely depend on its purity. So, to avoid contamination of the fluid, a separate nano fluid supply, collection and recirculation system need to be developed for application of nano fluid as cutting fluid. It is necessary to provide agitator to stir the fluid, homogenize and keep nano particles energized and restrict agglomeration of nano particles during application. Moreover to avoid nano particles agglomeration and to ensure homogeneity, fluid should be synthesized on ultrasonication machine in the solution of distilled water. The nano particle inclusion increase the density of basefluid and so it adversely affect the flow ability of cutting fluid. Literature review suggest 0.5% to 2.5% inclusion is desirable and provide positive results. Nano particles inclusion more than 2.5% can not provide significant change in machining performance.

4. RATIONALE

Tool life is defined as the elapsed period of cutting time when the average flank wear land of the tool is equal to 0.3 mm or the maximum flank wear land is equal to 0.6 mm. Reduction of co efficient of friction improves the tool life.

Co efficient of friction = $\mu = \frac{F}{N} = \frac{Fc \sin\alpha + Ft \cos\alpha}{Fc \cos\alpha - Ft \sin\alpha}$

Where, F is the frictional force due to the existence of normal load N. F_c and F_t are cutting force and thrust force and α is back rake angle.

It was observed from literature review that presence of nanofluid in emulsion reduces the frictional force significantly and so, coefficient of friction is also reduced considerably.

5. CONCLUSIONS

Increasing environmental and occupational health regulations, conventional method of cooling during machining pose challenges. Literature review suggested that nanofluid with effective cooling and lubricating properties look promising for the application as cutting fluid flood cooling. The following conclusions can be drawn from the present conceptual study.

1. It was observed that on increasing nano particles concentration, increase in density of the fluid adversely affects the cutting force. However surface finish was improved with increase in nano particles concentration.
2. Literature suggests that reduction in cutting forces and so, reduction in co efficient of friction and it improves tool life. Such substantial improvement in tool life can compensate the higher cost of nano fluid in the long run.
3. Experiments of various researchers with nanofluid proved that better lubrication and effective cooling at cutting edge improved the surface finish and reduced cutting forces that lead to increase in tool life, better surface integrity and reduction in power consumption during the process and hence can decrease the cost of cutting.

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