International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 5, July - 2012

Generalized Investigation of Near Dry Machining

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Abstract

In all machining processes, tool wear is a natural phenomenon and it leads to tool failure. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Metal cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions but the use of cutting fluid has become more problematic in terms of both employee health and environmental pollution. The use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances and to maintain workpiece surface properties without damages. Due to these problems, some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry machining and machining with minimum quantity lubrication (MQL).

This paper deals with the study of experimental investigation on the role of MQL on cutting temperature, for machining of AISI 1045 & AISI 9310 materials.

1.Introduction

In the continuous quest for reducing or eliminating the use of coolants in machining, only one process can offer a near-term solution for practical applications. This process uses a minimum quantity of lubrication and is referred to as “near-dry”. In near-dry machining (NDM), an air–oil mixture called an aerosol is fed into the machining zone. Compared to dry machining, NDM substantially enhances cutting performance in terms of increasing tool life and improving the quality of the machined parts. Small oil droplets carried by the air fly directly to the tool working zone, providing the needed cooling and lubricating actions. Aerosols are generated using a process called atomization, which is the conversion of bulk liquid into a spray or mist (*i.e.*, collection of tiny droplets), often by passing the liquid through a nozzle. An atomizer is an atomization apparatus; carburetors, airbrushes, misters, and spray bottles are only a few examples of the atomizers used ubiquitously. In internal combustion engines, fine-grained fuel atomization is instrumental to efficient combustion. Despite the name, it does not usually imply that the particles are reduced to atomic sizes. Rather, droplets of 1–5 μm are generated. Because MWF cannot be seen in the working zone, and because the chips look and feel dry, this application of minimum-quantity lubricant is called near-dry machining.

In short, NDM delivers a very small amount of coolant to a cutter’s edge in the form of an oil mist or aerosol, as opposed to traditional techniques of flooding the workpiece and tool with a substantial volume of liquid coolant. Just a tiny bit of that aerosol is left on the chips, workpiece and machine during the cutting operation.

2. Cutting Temperature In Near Dry Machining

The growing demand for high productivity of machining needs use of high cutting velocity & feed rates. Such machining inherently produces very high cutting temperature which, not only reduces tool life but also impairs the product quality. Application of cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions. It has been observed that the conventional type of use of cutting fluids is not compatible to effectively reduce the cutting temperature generated during high productivity. This increased temperature in turn manifests its affects in the various detrimental factors related to machining. Near dry machining presents itself as a compatible alternative for turning with respect to cutting temperature.

2.1 Cutting Temperature In Near Dry Machining For Aisi 1045

The cutting temperatures under MQL can be estimated from the moving heat source method [3]. Two heat sources and one heat loss are considered: the primary heat source in the shear zone, the secondary heat source at the tool-chip interface, and the heat loss due to the cooling effect from the air-oil mixture. The temperature rise in the chip is attributed to the primary heat source and the secondary heat source. The temperature rise in the tool is attributed to the secondary heat source and the heat loss due to cooling. The temperature change in the workpiece is caused by the primary heat source and the heat loss due to cooling. The heat loss intensity under MQL results from forced air convection, oil convection, and oil boiling. The forced air convection can be given as

$$q_{hl} = h\,(T_{flank} - T_0)$$

where;
h - average heat transfer co-efficient
T_{flank} – average flank temperature
T_0 - ambient temperature

The model was verified by comparing the predicted temperatures with the measured temperature with the thermocouple embedded under the tool insert. The results are shown in table 2 over cutting speed=45.75 to 137.25 m/min, feed=0.0508 to 0.1016 mm and depth of cut=0.508∼1.016 mm .

Tool insert	AISI 1045	
Thermal conductivity	Thermal conductivity	Thermal diffusivity
84.02 W/Mk	50.08 W/Mk	$0.134 \times 10^{-4}\ m^2/s$

Table 1: Material properties for the tool insert and the workpiece

Test No.	Temperature (^{0}C)	
	Experimental Data	Predictive Value
1	25	27
2	44	42
3	41	40
4	60	59
5	52	61
6	57	58
7	73	55
8	59	55
9	75	78

Table 2 Temperature comparison

2.2 Cutting Temperature In Ndm For Aisi 9310

M. M. Rahman, M M A Khan and N R Dhar [2] focused on the effect of minimal quantity lubricant on chip-tool interface temperature under different cutting velocity and feed rate in turning of AISI 9310 steel. Chip-tool interface temperatures were measured for three different cooling types such as dry, wet and MQL conditions.

Experiments were carried out by plain turning a 100 mm diameter and 710 mm long rod of AISI-9310 steel of common use in a lathe at different cutting velocities and feeds under dry, wet and MQL by vegetable oil conditions to study the role of MQL on the machinability characteristics of AISI 9310 steel alloy in respect of cutting temperature. The experimental conditions are listed in Table 3. The ranges of the cutting velocity (*Vc*) and feed rate (*So*) were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut was kept fixed to only 1.0 mm, which adequately served the purpose.

Machine tool	Lathe Machine, 15 hp	
	Work specimens	
Material	:AISI 9310 steel (C-0.12%, Mn-0.55%, P-0.025%, Si-0.25%, Ni-3.4%, S-0.025%, Cr-1.3%, Mo- 0.14%)	
Hardness (BHN)	:257	
Size	:φ100 × 710 mm	
Cutting insert:	:Uncoated carbide, TTS, SNMG 120408 (P-30 grade)	
	Composition: WC, TaC, TiC, Co	
	Grain size: 1.4 μm	
Tool holder	:PSBNR 2525M12	
Working tool geometry	:Inclination angle	: -6°
	Orthogonal rake angle	: -6°
	Orthogonal clearance angle	: 6°
	Auxiliary cutting edge angle	: 15°
	Principal cutting edge angle	: 75°
	Nose radius	: 0. 8 mm
	Process parameters	
Cutting velocity, V_c	:223, 246, 348 and 483 m/min	
Feed rate, S_o	:0.10, 0.13, 0.16 and 0.18 mm/rev	
Depth of cut, t	:1.0 mm	
Cutting Fluid	:Food-grade Vegetable Oil; Viscosity: 84 cP at 20°C and Flash Point: 340°C (open cup)	
MQL supply	:Air: 6 bar, Flow rate: 100 ml/h (through external nozzle).	
Environment	:Dry, Wet and Minimum Quantity Lubrication (MQL)	

Table 3 Experimental conditions for AISI 9310 steel

Figure 2 shows the effect of minimum quantity lubrication on average chip-tool interface temperature under different cutting velocity and feed rate as compared to dry and wet conditions. However, it is clear from the aforementioned figures that with the increases in *Vc* and *So*, average chiptool interface temperature increases as usual due to increase in energy input. The roles of variation of process parameters on percentage reduction of average interface temperature due to MQL have not been uniform. This may be attributed to variation in the chip forms particularly chip-tool contact length (*CN*) which for a given tool widely vary with the mechanical properties and behaviour of the work material under the cutting conditions. Post cooling of the chips by MQL jet is also likely to influence *θavg* to some extent depending upon the chip form and thermal conductivity of the work materials.

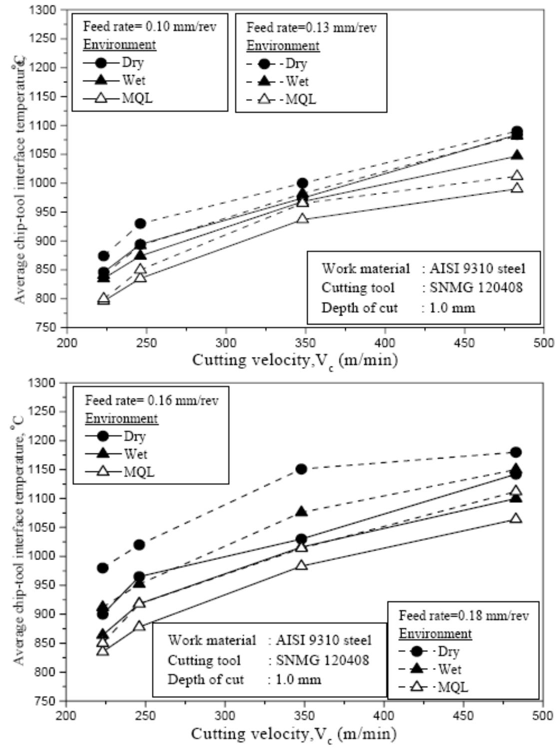

Figure 2**:** Variation in *θavg* with that of *Vc* and *So* in turning steel by SNMG insert under dry, wet and MQL cooling conditions at 0.10, 0.13, 0.16, and 0.18 mm/rev,

Based on the results of the present experimental investigation, the following conclusions were be drawn:

i. MQL provided significant improvements expectedly, though in varying degree, in respect of the *Vc* and *So* range undertaken mainly due to reduction in the average chip tool interface temperature. Flood cooling by soluble oil could not control the cutting temperature appreciably and its effectiveness decreased further with the increase in cutting velocity and feed rate.

ii. The present MQL systems enabled reduction in average chip-tool interface temperature up to 10% depending upon the cutting conditions and even such apparently small reduction, unlike common belief, enabled significant improvement in the major machinability indices.

3. Conclusions

Based on the study carried out it can presumed that MQL enabled sizable reduction in the cutting zone temperature and favorable changes in the tool-chip interface which helps in the reduction of friction, built up edge formation, thermal distortion of the work & wear of cutting tool.

MQL will also deliver on the two prime drivers. From a total cost of ownership perspective, which considers machine cost, downtime, maintenance, floorspace, electricity usage, coolant management and related factors, MQL will yield an improvement versus comparable wet operations. As for environmental impact, MQL can be a key factor in any plant's efforts in delivering no manufacturing by-products to landfill.

There are also numerous other beneficial results that can be realized with the implementation of near dry machining, which can be enumerated as follows.

Sensors, switches and electronics last much longer. Automation, a key component of any plant's machining processes, relies on switches, servos and other electronic elements that don't particularly like wet environments. In MQL, the plant may see a remarkable reduction in nuisance faults because there is no coolant that can find its way into electronic components. This ultimately leads to improved system uptime, which is vital for any high-production manufacturer. In addition, conveyors delivering parts in and out of cells will no longer need coolant-collecting pans underneath them, because there's no coolant to drip off of the MQL-machined parts being transferred. In wet operations, coolant left in conveyor catch pans for an extended period of time can become stagnant and malodorous.

CMMs are welcome on the shop floor without enclosures. Because of the inherent cleanliness of MQL and temperature-controlled facilities, CMMs can be located on the shop floor without enclosures, reducing installation costs and enabling the CMMs to be positioned closer to the machines.

Chips will go straight to the recycler. Because the chips produced with MQL operations are delivered to each machine's hopper essentially dry, the need for time-consuming and costly recovery operations to separate coolant from chips is eliminated. Chips can be removed from each machine's hopper and collected for delivery straight to the recycler.

MQL helps with the plant's flat-floor efforts. Wet-machining systems carry a host of facility requirements. Support facilities not only need to provide coolant (via a stand-alone and/or a large central coolant system), but also must remove and/or contain the coolant. This ranges from a minimum of engineered floor drainage systems to contain spillage to lengthy trenches (or flumes) cut into the foundation for coolant/chip containment and flow out of the cell. Because MQL machines are essentially self-contained, there is no need to create unique drainage and flume systems.

Assembly, if any, can happen close to machining cells. Wet machining operations have traditionally been quarantined in some secluded, perhaps even enclosed area of the facility so as not to contaminate assembly lines. The only physical element that can separate machining area and assembly is a staging and storage area for machined components. Bringing machining close to assembly in this way greatly reduces wasted part travel throughout the facility. It also allows tighter inventory control because the staging area, with its set number of storage racks, acts as a lean manufacturing supermarket that feeds assembly. The opportunity to over-produce and fall victim to hidden factory wastes will become greatly reduced.

From the steps that must be taken to implement NDM, it is apparent that, to make this technology reliable, environmentally friendly and cost efficient, the whole picture has to be considered. First of all, a machine tool (manufacturing cell, production line *etc*.) and cutting tools should be designed specifically for NDM. Although some machine tools have been retrofitted for NDM, retrofitting an existing machine does not appear to be an attractive alternative.

Ideally, the implementation of NDM starts from the part design, which should make NDM easier in terms of chip removal and evacuation. For example, deep blind holes are to be avoided giving preference to core holes; threads should be designed to make them suitable for form rather than cutting threading taps; preference should be given to open flat faces suitable for face and interpolating milling; parts (particularly aluminium parts in the automotive industry) should be designed to be less susceptible to thermal distortion due to heat generated in machining with the aid of FEM thermal distortion analysis *etc*. The choice of the part material and its metallurgical state should also be made, accounting for machinability and susceptibility to thermal distortion. Chip-breaking problems should be one of the prime concerns as, if this problem is not resolved, it can easily make the whole NDM project impractical.

As discussed above, the cutting tools should be designed for NDM. Not only should the aerosol-supply channels be suitable, but also the tool geometry, tool materials and design of the tool body (back tapers, reliefs, undercuts and supporting elements) should be optimized for NDM. Additional procedures in tool setting and maintenance as well as additional equipment for aerosol verification must be implemented and followed.

The success of NDM can be achieved if all components of machining or manufacturing system are suitable for this technology.

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