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REVIEW ARTICLE

A REVIEW ON ALTERNATIVES IN COOLING OF CUTTING ZONE DURING TURNING

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ABSTRACT

Alternatives in cooling of cutting zone during metal cutting have been paid more attention in order to minimize the flank wear, surface roughness and cutting zone temperature. The usage of coolant lowers the cutting zone temperature which minimizes the wear of cutting tool and hence, the surface finish of the product is good. Several technologies for cooling of cutting zone have been developed in recent years for controlling the temperature in the cutting zone like cryogenic cooling, solid coolants/lubricants, High Pressure Coolants (HPC), internal tool cooling and use of compressed air. Many researchers and scientists developed lot of experimental studies to analyze the effect of various methods of cooling of cutting zone in order to minimize the wear of cutting tool and surface roughness are reviewed in this paper.

INTRODUCTION

Ahsan Ali Khan and Mirghani (2008) used specially designed tool holder in which liquid nitrogen was converted into gaseous state before coming in contact with the tool insert and nitrogen was made to flow just beneath the insert through a small hole. The tool life for various cutting speed with conventional method of cooling and cryogenic cooling had been obtained. High-pressure coolant delivery is an upcoming technology in turning that delivers a high-pressure fluid to the tool and machined material. The high pressure fluid allows a better penetration of the fluid into the tool– work-piece and tool–chip contact regions. As the application of conventional fluids creates some techno- environmental problems, investigations on the use of biodegradable cutting fluids has come into existence. As the water vapor and air are cheaper, eco-friendly and pollution free, they are used as economical coolant and lubricant during machining. In addition to the above method of cooling, sometimes nitrogen gas and liquid nitrogen were delivered with high pressure and directed into the tool-chip interface.

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Cryogenic cooling in turning

It was identified that with conventional coolant the tool life was 13.45 min at 100 m/min speed and 0.5mm depth of cut, whereas under same cutting conditions in cryogenic cooling, the tool life was 57.45 min. The experimental result showed that the application of cryogenic coolant has increased the tool life by 4.27 times. Venugopal *et al.* (2007) conducted an experiment while machining Ti-6Al-4V alloy using uncoated micro-crystalline K20 tungsten carbide inserts at 70m/min speed, 0.2mm/rev feed and 2mm depth of cut, with cryogenic cooling. The wear of cutting inserts with cryogenic cooing had been compared with dry cutting and wet turning. It was found from the analysis that, maximum value of flank wear reduces 3.4 times as compared to dry turning and 2 times as compared to wet turning. It was found from the results that such benefits were decreased under high velocities of 100 and 117 m/min possibly due to improper penetration of liquid nitrogen in the chip–tool interface. Flaking of the rake surface just at the end of the crater wear region was observed especially under cryogenic machining condition. This is attributed to higher thermal gradient at the end of crater contact. Ahmeda *et al.* (2007) proposed two different designs for cryogenic cooling with modified tool holder. In design 1, the gas will be directed towards the cutting edge of the tool, to cool the newly generated chips. This will enhance the chip brittleness for easy chip breaking. In design 1, the fluid exit is made closer to the tip of the cutting tool. In design 2, the fluid exit is made away from the tip of the cutting tool as a result the discharging gas is directed away from the work-piece. This design was useful for those materials in which excessive cooling had a negative effect on their ductility. It was noticed clearly that design 2 exhibited better wear resistance in comparison to design 1. This is due to the fact that in the case of design 2, the work-piece was cooled by the nitrogen outflow, which discharges the evaporated gas away from the cutting edge and the chip. The design 2 was recommended for cutting materials that have strong temperature–ductility relations. The cutting zone temperature developed during turning has been minimized with internal cooling of cutting tool with conductive and convective mode of heat transfer. Heat pipes are passive devices with very high thermal conductance. They are used to transport the heat by means of evaporation and condensation of an appropriate fluid.

High pressure coolant method

Diniz Eduardo Anselom and Micaroni Ricardo (2007) studied the wear of cutting insert in finish turning of AISI 1045 steel using coated carbide tools under high-pressure fluid (with high and low flow rate), dry cutting and conventional fluid application (low pressure, high flow rate, no specific direction). The three directions of high-pressure fluid were used in the analysis such as coolant directed towards the chip–tool interface (tool rake face), coolant directed towards the work-piece– tool interface (flank face) and coolant directed towards both flank and rake face. It was found from the investigation that, the longest tool lives were obtained when fluid was applied either simultaneously on the rake and flank faces with high pressure and high flow rate, or solely on the flank face with high pressure and low flow rate. It was identified that, when high pressure fluid was injected on the rake face, the adhesion between chip and tool was strong, causing the removal of tool particles. When the adhered chip material was removed from the tool by the chip flow, it resulted in a large crater wear as the fluid was not able to penetrate between chip and tool to perform lubrication, since no fluid elements were found on the crater wear region. Emmanuel *et al.* (2007) identified that, the surface roughness value varied steadily with pro-longed machining under high coolant supply pressure. The values of the surface roughness recorded in all the cutting conditions investigated are generally well below the stipulated rejection criterion of 1.6 µm.

It was noticed that, the finish of the machined surface is not affected while machining Ti–6Al–4V alloy with high coolant pressures, notwithstanding the possibility of water-jet abrasion of the machined surface during the machining process. Also it was noticed that, there is no evidence of sub-surfaced effects such as cracks, laps, visible tears or shear deformation after machining Ti–6Al–4V alloy with both conventional and high-pressure coolant supplies. It was found from the investigation that, there is a hardening of machined surface after machining with conventional coolant flow due to irregular cooling effect that promotes rapid quenching effect. Nandy et al (2008) performed the studies on high pressure cooling in turning of Ti–6Al–4V which lead to better cooling and more chip curling with smaller broken chips.

It is reported that, there was a significant reduction in chip–tool contact length with neat oil as well as water-soluble oil. This attributed to the lifting of the chip leading to chip curling under the action of the high-pressure coolant jet. It was found that, high-pressure neat oil significantly provided beneficial effect on tool life over conventional wet environment. But most importantly high-pressure water-soluble oil provides drastic improvement on tool life throughout the experiment. Also it was noticed that, the cutting force reduced significantly under high-pressure cooling environment.

Solid coolant method

Dilbagh Singh and Rao (2008) conducted an experiment in the machining of thoroughly hardened AISI 52100 steel with ceramic inserts by using solid lubricants like graphite and molybdenum disulphide. It was observed that at high cutting speed range, the solid lubricants were more effective. Also it was noticed that surface roughness was found to be decreasing with the increase of the cutting speed up to 125 m/min and after that it started increasing at high cutting speeds. This could be due to the reduction in the cutting forces at high speed. It was found that, solid lubricant assisted hard turning produced low value of surface roughness as compared to the dry hard turning. It was found that, there is a decrease in surface roughness value by 8%–10% due to graphite and by 13%–15% due to molybdenum disulphide. The lower values of surface roughness produced by molybdenum disulphide can be attributed to its strong adhesion as compared to graphite. Vamsi Krishna and Rao Nageswara (2008) used solid lubricants (a mixture of graphite and boric acid with Society of Automotive Engineers (SAE) 40 oil) during the turning of EN8 steel work-piece with cemented carbide tool. The cutting forces were measured to evaluate the lubricating properties of solid lubricants.

It was evident that use of solid lubricant reduced the cutting forces compared to dry and wet machining. This performance of solid lubricants was due to its lattice layer structure that allows it to act as an effective solid lubricant film. It was also observed that the rate of flank wear was less with solid lubricant assisted machining compared to wet and dry machining. This may be due to the solid lubricant mixture, which created a thin film of lubrication on the work-piece and caused reduction of flank wear. It was noticed that, 20% boric acid in SAE 40 oil provided better performance for the selected tool-work combination and cutting conditions. Deep Mukhopadhyay *et al*. (2007) performed solid lubricant assisted machining in turning AISI 1040 steel to control the machining zone temperature without polluting the environment. Experiments were carried out to study the effect of solid lubricants on surface finish and chip thickness. It was observed from the experimental results that the minimum surface roughness was observed at 12 degree rake angle during molybdenum disulphide assisted machining. The corresponding rake angle for wet machining was 8 degree. It was clear that the higher value of the optimum rake angle was observed during solid lubricant assisted machining. Thus, the tool can be sharper in the presence of solid lubricant assisted machining. It is well known that if the tool is sharp, it is favorable for easy chip formation, so that the surface finish of the products produced is good.

Air/vapor/gas coolant method

Tae Jo Ko *et al*. (1999) used an air-cooling system with air-vortex flow arrangement in order to reduce the heat generated at the tool–chip interface during the turning of heat-treated SAE 52100 bearing steel. The air was initially ejected towards the cutting region at 0oC. It was found that, tool wear was less compared to that in dry cutting. However, it was noticed that, the performance was not superior to that of flood cooling in terms of tool wear. Further an air–oil-cooling system was used where an oil coolant was supplied through the cooling nozzle. Thus in this way mist coolant was supplied to the cutting area at a temperature of 0oC, providing cooling and lubrication effects simultaneously. By changing to air–oil cooling, tool chipping was eliminated and tool wear was reduced by over 13% relative to air-jet cooling. This performance was found even better than flood cooling. Liu Junyan *et al.* (2007) performed an experimental study in turning of ANSI1045 steel with cemented carbide tools in the presence of water vapor, carbon-di-oxide gas, oxygen gas and mixture of vapor and gas as cooling medium, it was found that as compared to dry cutting and wet cutting, cutting force was reduced by 20–40% and 10–15%, respectively, with application of water vapor, gas and mixture of vapor and gas as lubricant. When water vapors were used as coolant and lubricant, the cutting temperature was lower (<800oC at cutting speed of 117.6m/min) than that of other lubrication. It was noticed that with the application of water vapor at high cutting speed, the tool life increases two times that of dry cutting.

Stanford et al (2008) conducted an experiment in turning of EN32b plain carbon steel with uncoated turning tools under flood coolant, compressed air blast (20% oxygen at 0.27MPa), ambient temperature nitrogen gas environment (6%oxygenat0.27MPa), cold nitrogen gas (-40oC start temperature, 0%oxygen at 0.27MPa), liquid nitrogen gas environment (0.27MPa, 0% oxygen), and dry cutting conditions. It was revealed that uncoated tools used in nitrogen-cutting environment provided a 55% reduction in crater wear and 30% reduction in flank wear as compared to that under other environment. From the results it is clear that nitrogen-cutting fluids assist tool life and should be considered as an alternative to flood coolants while turning EN32b steel. Nitrogen environment gave the best results because of tighter chip curl and shorter contact lengths compared to the ambient temperature environments.

Allied cooling process

Noorul Haq and Tamizharasan (2006) conducted a parametric study in hard turning operation to analyze the effects of different heat pipe parameters such as diameter of pipe, length of heat pipe, magnitude of vacuum in the heat pipe and the material of heat pipe. The heat pipe parameters were optimized using Taguchi's Design of Experiments and a confirmation test was conducted by employing the heat pipe fabricated with best values of parameters. It was found that the temperature field was reduced by 5% due to the use of heat pipe. Also it was noticed that there is a significant increase in the tool life by reducing the tool wear by about 6%. Also it was concluded that the heat pipe completely eliminates the application of cutting fluids in hard turning with a considerable reduction in tool wear and improvement in surface finish. Jie Liu and Kevin Chou (2007) investigated the cutting tool temperature with the use of heat pipe assisted composite machining. Heat pipe cooling was implemented in the machining test and its effects on tool temperature reductions were simulated and compared with the experiment.

It was found that the average tool-chip contact temperatures are generally alleviated by heat-pipe cooling, except at the combination of high speed and high feed. For the machining conditions and heat pipe settings tested, the average tool-chip contact temperatures are reduced, up to about 10°C. Also it was concluded that, increasing the heat-pipe volume and decreasing the heat pipe distance to the heat source, enhances the effectiveness of heat-pipe cooling.

Richard Chiou *et al.* (2007) analyzed the effects of an embedded heat pipe system during machining operation. A new embedded heat pipe technology had been developed to effectively remove the heat generated at the tool-chip interface during machining, thereby reduced the cutting tool wear and prolong the tool life. Experiments were carried out to characterize the temperature distributions when performing turning experiments using a cutting tool installed with an embedded heat pipe. The simulation using ANSYS showed that the temperature near the cutting edge dropped significantly due to the use of embedded heat pipe during machining.

Conclusion

This review paper focused on various ways of cooling the cutting zone during turning. Researches did extensive work in the field of cooling and allied techniques. In this way we have reviewed a new alternative study in cooling of cutting zone using positive approach to keep temperature rise within limit and to get improved machining characteristics.

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