THE EFFECT OF APPLYING HIGH-PRESSURE COOLANT (HPC) JET IN MACHINING OF 42CrMo4 STEEL BY UNCOATED CARBIDE INSERTS

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Abstract: *To avoid surface distortion and to improve tool life, machining of alloy steel and other hard materials under high speed-feed condition requires instant heat transfer from the work-tool interface where the intensity of cutting temperature is the maximum. Conventional cooling is completely unable and other special techniques like MQL and cryogenic cooling are not suitable in context of product quality and cost effectiveness. Supply of high-pressure coolant (HPC) with high velocity may provide the best control to reduce cutting temperature and tool wear as well as increase tool life. This paper deals with an experimental investigation on the effect of high-pressure coolant on temperature, tool wear, surface roughness and dimensional deviation in turning 42CrMo4 steel by uncoated carbide inserts and comparing it with dry condition. It is observed that the cutting temperature and tool wear is reduced, tool life is increased, surface finish is improved, and dimensional deviation is decreased with the use of high-pressure coolant.*

Keywords: *High-pressure coolant (HPC), Alloy steel, Temperature, Wear and Product quality*.

INTRODUCTION

During machining, a tool penetrates into the work piece because of the relative motion between the tool and the work piece, deforms the work material plastically and removes the material in the form of chips. Plastic deformation of the work material, rubbing of the tool flank with the finished surface and friction between tool rake face and flowing chips produces huge amount of heat and intense temperature at the chip-tool interface. A major portion of the energy is consumed in the formation and removal of chips. Energy consumption increases with the increase in cutting velocity, feed and depth of cut as well as strength and hardness of work material. 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 and lower the tool life.

To remove the heat generated at the cutting zone, in industries, usually flood or conventional coolant is applied from the overhead position. During machining, especially of hard materials, much heat is generated by the friction of the cutter against the work piece, which is one of the major causes of reduction in tool hardness and rapid tool wear[1]. For this reason, conventional coolant is often used on the cutting tool for bulk cooling and to prevent overheating. However, the main problem with conventional coolant is that it does not reach the actual chip-tool interface where the maximum temperature attains[2]. The extensive heat generated evaporates the coolant before it can reach the cutting area, makes a semi conductive vapor barrier and consequently prevents heat conduction. The high cutting forces generated during machining induce intensive pressure at the cutting edge between the tool tip and the work piece. 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. More over conventional coolant is one of the major sources of pollution in the industries.

Controlling of high cutting temperature in high production machining, some alternative methods have already been experimented in the different parts of the world. Cutting forces and temperature have been found to reduce while machining steel with tribologically modified carbide inserts[3]. Application of CO_2 in the form of liquid jet at high pressure also enables some reduction in cutting forces[4]. Cryogenic machining with liquid nitrogen[5, 6] and machining with Minimum Quantity Lubrication (MQL) [7, 8] have improved machinability of steel to a certain extent under normal cutting conditions. It has also been reported that the machining of steel with liquid nitrogen improves the machinability index[5, 6] but cryogenic machining is costly due to high cost of liquid nitrogen[5, 6]. Also accelerated notch wear on the principal flank of the carbide insert has been observed at nitrogen rich atmosphere of cryogenic machining.

The concept of high-pressure coolant may be a possible solution for high speed machining in achieving intimate chip-tool interaction, low cutting temperature and slow tool wear while maintaining cutting forces/power at reasonable levels, if the high pressure cooling parameters can be strategically tuned. With the use of high-pressure coolant during machining under normal cutting conditions, the tool life and surface finish are found to improve significantly, which is due to the decrease in heat and cutting forces generated[9-11]. Mazurkiewicz[11] reported that a coolant applied at the cutting zone through a high-pressure jet nozzle can reduce the contact length and coefficient of friction at chip-tool interface and thus can reduce cutting forces and increases tool life to some extent. High-pressure coolant injection technique not only provides reduction in cutting forces and temperature but also reduces the consumption of cutting fluid by 50%[12, 13].

The review of the literature suggests that high-pressure cooling provides several benefits in machining. However, there is a need to improve machining conditions providing credible data for in depth understanding of high-pressure coolant supplies at the chip-tool interface and integrity of machined components, especially for hard materials. The main objective of this research is to evaluate the effectiveness of high-pressure coolant in improving the cutting parameters on harder work material. The performance of high-pressure coolant is investigated by focusing on cutting temperature, tool wear, tool life, surface finish, and dimensional deviation and compares the effectiveness of high-pressure coolant with that of dry machining.

EXPERIMENTAL INVESTIGATIONS

Experiments have been carried out by plain turning of 42CrMo4 steel rod (Ø 220x520 mm) in a powerful and rigid lathe at different cutting velocities (V) and feeds (f) under both dry and high-pressure coolant (HPC) conditions. The experimental set-up used for the present purpose has been shown in Figure 1. The machinability characteristics of that work material mainly in respect of cutting temperature, tool wear, tool life, surface roughness and dimensional deviation have been investigated to study the role of high-pressure coolant. The ranges of the cutting velocity (V) and feed (f) were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut (d), being less significant parameter, was kept fixed. The following cutting parameters have been chosen for the present experiment:

Cutting speed, V: 93,133,186,266 and 193 m/min
Feeds, f: 0.10, 0.14, 0.18 and 0.22 mm/rev
Depth of cut, d: 1.0 and 1.5 mm

Standard Sandvik PSBNR 2525M12 tool holder was used to hold indexable Sandvik cutting inserts SNMG and SNMM so that the geometry becomes (-6°, -6°, 6°, 15°, 75°, 0. 8 mm).

The high velocity stream of high-pressure coolant jet (80 bars) is impinged along the auxiliary cutting edge of the insert, so that the coolant reaches as close to the chip-tool and work-tool interfaces as possible and effectively cool the tool and the work material at the hot cutting zone.

The average cutting temperature was measured by simple but reliable tool-work thermocouple technique with proper calibration[14]. Figure 2 shows the photographic view of the calibration setup. Figure 3 shows the calibration curve obtained for the tool-work pair with tungsten carbide as the tool material and steel undertaken as the work material. Machining has been interrupted at regular interval and the tool has unclamped to measure width of wear land on the principal and auxiliary flank. Tool wear is monitored under optical microscope (Carl Zeiss, Germany) fitted with micrometer of least count 10 µm. As per ISO standard tool rejection criteria is selected as the growth of wear VB=300 µm on its principal flank. When the tool wear reaches to its limiting value, it is inspected under scanning electron microscope (Philips XL30) to study the wear mechanism. Surface roughness is measured along the longitudinal direction of the turned job with the help of a Talysurf roughness checker (Surtronic 3^+, Tailor rank Hobson, UK). A complete pass is performed with a fresh edge of the tool and deviation in dimension was measures with the help of a digital dial gauge of least count 10 µm.

RESULTS AND DISCUSSION

Reduction of friction between the chip-tool and work-tool interface is very important in cutting operation, as reduction in kinetic coefficient of friction not only decreases frictional work, but also decreases the shear work as well. Usually cutting temperature increases with the increase in process parameters causing decrease in hardness of the contact layer of the work piece and also the tool material. The higher the cutting speed and feed, the higher the temperature is, due to high energy input. Machining high temperature has detrimental effect on cutting tool and product quality. So it is needed to control

Figure 1: Photographic view of the experimental set-up

Figure 2: Photographic view of the calibration set-up

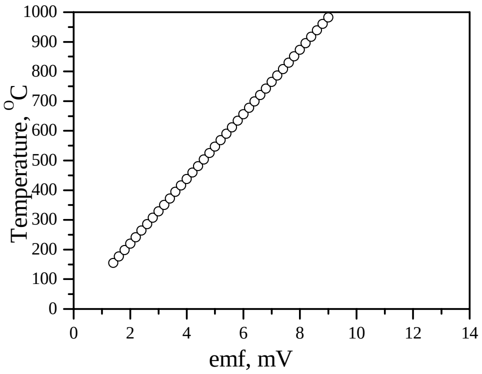
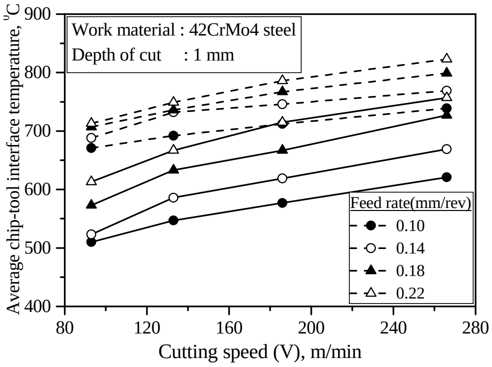


Figure 3: Temperature calibration curve for carbide and 42CrMo4 steel

the cutting temperature to achieve an effective cutting condition and to improve machinability index. The high-pressure coolant system reduces the cutting temperature and provides a very favorable effect. The effect of HPC on average chip-tool interface temperature at different cutting speed and feeds under both dry and HPC conditions has been shown in Figure 4. It is clear from Figure 4 that during machining at lower cutting speed the cooling effect is more as the nature of chip-tool contact is plastic-elastic. Initially the chip tool contact is plastic but when the chip leaves the tool the nature of contact is elastic. High velocity jet of HPC is easily dragged in the elastic contact zone. With an increase in cutting speed the chip makes fully plastic or bulk contact with the tool rake surface which prevents from entering of jet into the hot chip-tool interface. As a result, under higher speed, rate of reduction of temperature is less in comparison with lower speed. HPC cooling effect also improved to some extent with the decrease in feed particularly at lower cutting speed. At lower chip velocity, the thinner chips are pushed up by the HPC jet coming from opposite direction of chip flow and enable it come closer to the hot chip-tool contact zone to remove heat more effectively. With an increase in feed curl radius of the thick chip is increased. For this plastic contact length is increased and HPC jet becomes less effective. At high speed, little time is provided for the cutting fluid to penetrate, the coolant might not get enough time to remove the heat accumulated at the cutting zone resulting in less reduction in temperature under HPC condition. The rate of frictional heat generation is reduced due to the lubrication of the chip as it passes over the tool and lubrication between work-tool interfaces.



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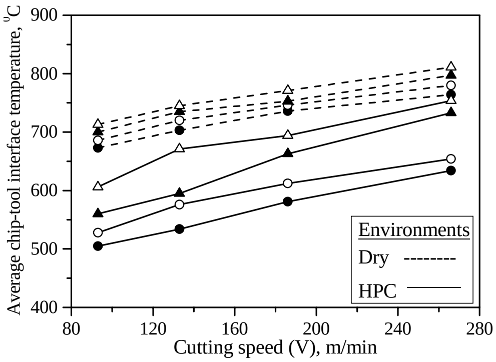

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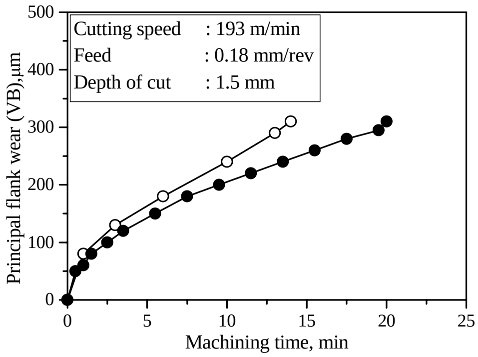
Figure 4: Variation in temperature with cutting speeds at different feeds under dry and HPC conditions

Under usual cutting conditions the cutting edge of a form stable cutting tool is wear out due to continuous interaction and rubbing between the chip and the tool and between the work and the tool. After the tool has been used for some times, wear land is appeared at the flank of the tool below the cutting edge extending approximately parallel to the cutting edge. The maximum or predominant wear is taken place in the zone where the energy input is greater. The nature of cutting tool wear under condition of mechanical wear depends on the distribution of frictional work on the contact surfaces. For high speed machining, diffusion wear is taken place both at the flank and face surfaces and depending on the magnitude and nature of temperature distribution. Turning carbide inserts having enough strength; toughness and hot hardness generally fail by gradual wears. With the progress of machining the tools attain crater wear at the rake surface and flank wear at the clearance surfaces. The useful life of the tool is limited by tool wear. The principal concern of metal cutting research has been to investigate the basic mechanism of wear by which the life of the tool is governed. The life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value (VB) of its principal flank wear reaches a limiting value, like 300 µm. Cost of manufacturing product are affected by life of the cutting tools. Therefore, attempts should be made to reduce the rate of growth of flank wear (VB) in all possible ways without much sacrifice in MRR.

The growth of average principal flank wear, VB and average auxiliary flank wear, VS with machining time at high cutting velocity (193 m/min) and depth of cut (1.5 mm) by both the inserts under dry and high-pressure coolant conditions have been shown in Figure 5 and Figure 6 respectively. It is observed that while dry cutting



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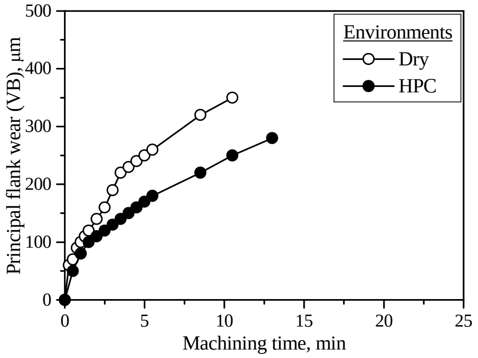

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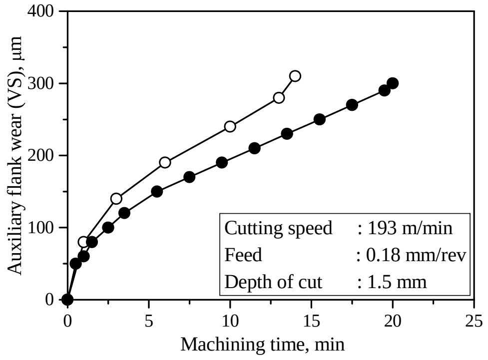
Figure 5: Growth of average principal flank wear (VB) with machining time under dry and HPC conditions



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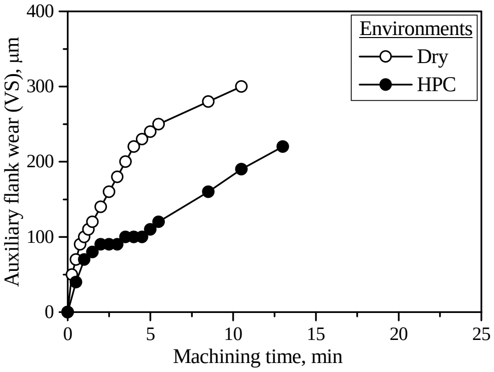

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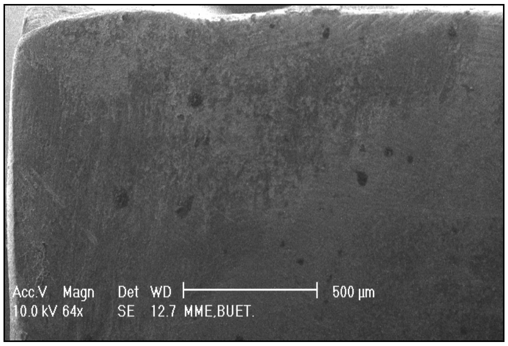
Figure 6: Growth of average auxiliary flank wear (VS) with machining time under dry and HPC conditions

principal flank wear and auxiliary flank wear is more than that of HPC condition. Tool wear reduces due to substantial reduction in cutting zone as well as flank temperature and lubrication in the interface by HPC jet. Under both the condition initially the wear rate is more for both SNMG and SNMM insert because of sharp edge of the insert rapidly break down due to plastic deformation and consequential temperature rise. After some time the wear process is more or less uniform. For both the cases, severe sparking is observed and the insert wear out rapidly in the last pass. Before the appearance of spark, the wear data taken is plotted shown in Figure 5.

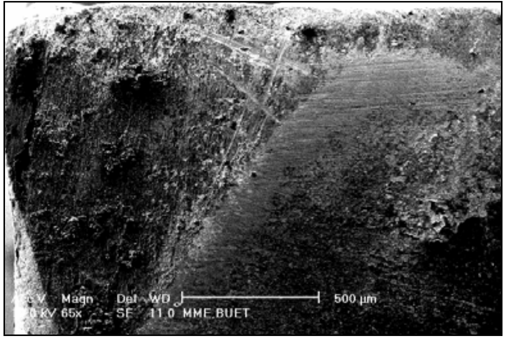
Auxiliary flank wear (VS), though occurs less intensively, also plays significant role in machining by aggravating dimensional inaccuracy and roughness of the finished surface. It appears from Figure 6 that auxiliary flank wear (VS) for both SNMG and SNMM insert have also decreased sizably due to high pressure jet cooling.

Principal and auxiliary flank surfaces of the tool tip have been observed under SEM to see the actual effects of different environments on wear of the carbide insert after being used for machining steel over reasonably long period. At the starting of last pass severe sparking is observed and the tool wears out rapidly. The SEM views principal and auxiliary flank of the worn out SNMG insert after about 14 minutes of dry machining and 20 minutes machining under HPC conditions have been shown in Figure 7 and Figure 8 respectively. Machining under dry condition with SNMM insert shown in Figure 9 and Figure 10, welding of work material over principal flank of the insert and scratching mark due to re-cutting of the chips is observed. No groove or notch wear is found under both the environments. Under all the environments, scratch marks appears in the flanks. There have also been some indications of adhesive wear in the insert. Some plastic deformation and micro chipping are found to occur under dry and HPC machining. Effective temperature control by HPC almost reduces the growth of notch and groove wear on the main cutting edge. It has also enabled the reduction in the auxiliary notch wear. Further the figure clearly shows reduced average flank wear, average auxiliary flank wear and crater wear under High Pressure Coolant condition.

The major causes behind development of surface roughness in continuous machining processes like turning, particularly of ductile metals are (i) regular feed marks left by the tool tip on the finished surface (ii) irregular deformation of the auxiliary cutting edge at the tool-tip due to chipping, fracturing and wear (iii) vibration in the machining system and (iv) built-up edge formation, if any. Figure 11 shows the variation in surface roughness with cutting velocity under dry and HPC conditions. As HPC reduces average auxiliary flank wear and notch wear on auxiliary cutting edge, surface roughness is observed comparatively lower under High Pressure Coolant conditions. However, it is evident that HPC improves surface finish depending upon the work-tool materials and mainly through controlling the deterioration of the auxiliary cutting edge by abrasion, chipping and built-up edge formation.



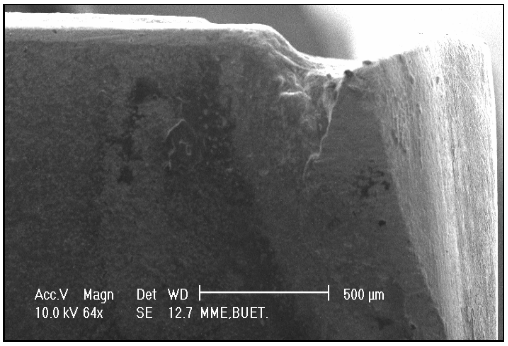
Dry condition, 14 min



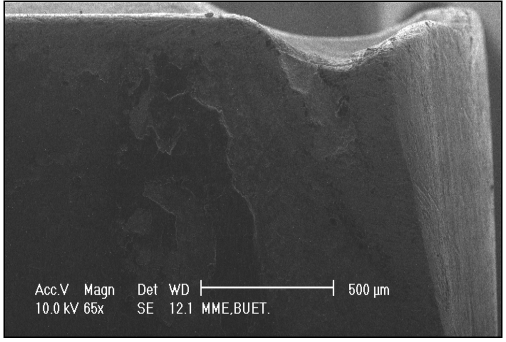
HPC condition, 20 min

Figure 7: SEM views of principal flank of worn out tip of SNMG insert

Surface roughness gradually increases as usual with the machining time as can be seen in Figure 12, due to gradual increase in auxiliary flank wear (VS). Again it is observed that the rate of increase in surface roughness decreases to some extent when machining is done under HPC condition which not only reduces the auxiliary flank wear but also possibility of built-up edge formation due to

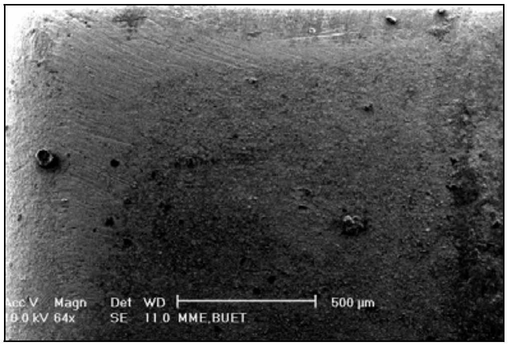


Dry condition, 14 min

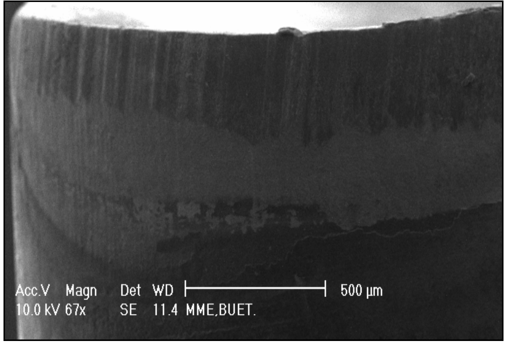


HPC condition, 20 min

Figure 8: SEM views of auxiliary flank of worn out tip of SNMG insert



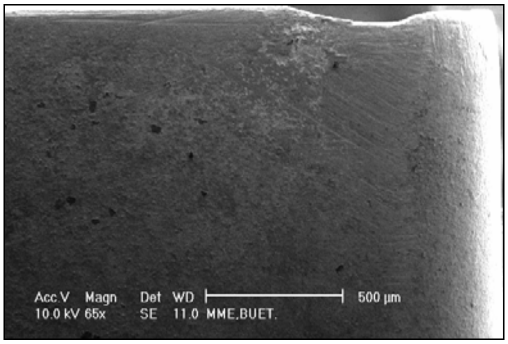
Dry condition, 10.5 min



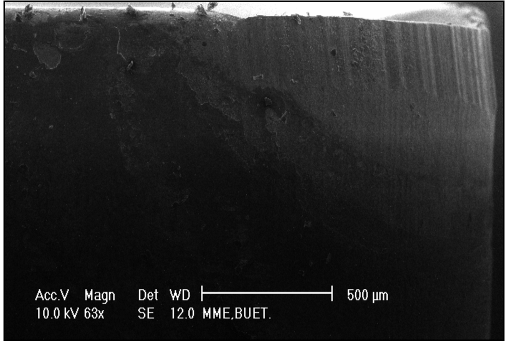
HPC condition, 13 min

Figure 9: SEM views of principal flank of worn out tip of SNMM insert

reduction in temperature. It appears from Figure 12 that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips. High Pressure Coolant appeared to be effective in reducing surface roughness.

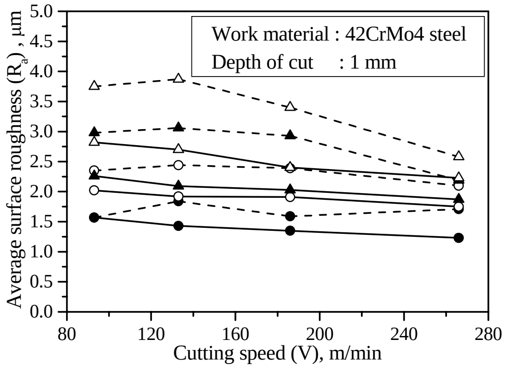


Dry condition, 10.5 min



HPC condition, 13 min

Figure 10: SEM views of auxiliary flank of worn out tip of SNMM insert



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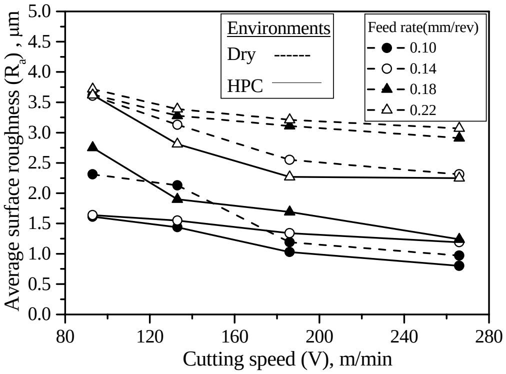

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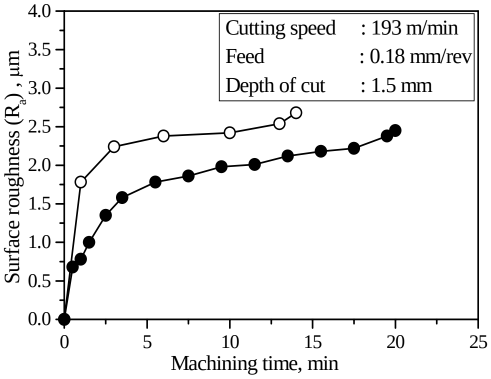
Figure 11: Variation in surface roughness with cutting speeds at different feeds under dry and HPC conditions



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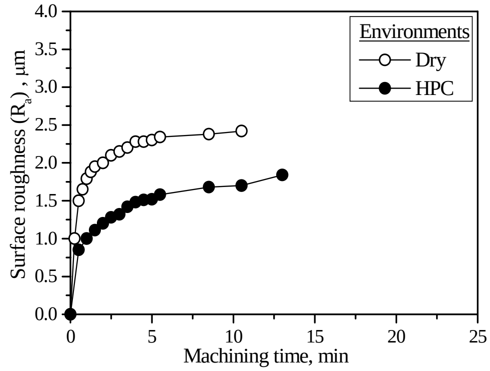

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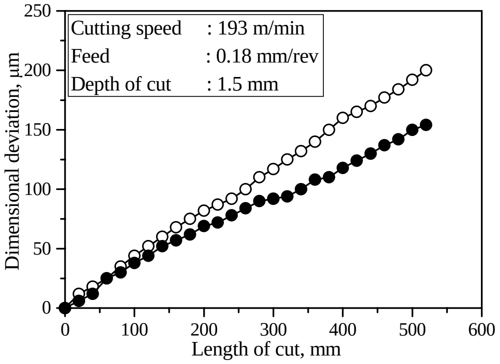
Figure 12: Surface roughness developed with progress of machining under dry and HPC conditions



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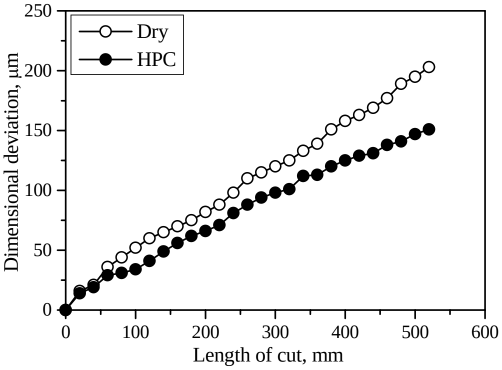

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Figure 13: Dimensional deviation observed after one full pass turning under dry and HPC conditions

High Pressure Coolant provides remarkable benefit in respect of controlling the increase in diameter of the finished job with machining time as can be seen in Figure 13. In plain turning the finished job diameter generally deviates from its desired value with the progress of machining i.e. along the job-length mainly for change in the effective depth of cut due to several reasons which include wear of the tool nose, over all compliance of the Machine-Fixture-Tool-Work (M-F-T-W) system and thermal expansion of the job during machining followed by cooling. Therefore, if the M-F-T-W system is rigid, variation in diameter would be governed mainly by the heat and cutting temperature. With the increase in temperature the rate of growth of auxiliary flank wear and thermal expansion of the job increases. High Pressure Coolant takes away the major portion of heat and reduces the temperature resulting decrease in dimensional deviation desirably.

CONCLUSIONSHigh-pressure coolant jet not only reduces chip-tool and work-tool interface temperature but also reduces the heat generation by its effective oil film lubrication under all the investigated speed-feed combinations.

ii. High-pressure coolant has significantly reduced flank wears as a result improved tool life. After machining 14 and 20 minutes with SNMG insert under dry and HPC condition respectively, severe spark is observed and cutting tools undergo severe plastic deformation as well as rapid tool wear.

iii. Surface finish improves under high-pressure coolant condition in turning 42CrMo4 steel. Efficient chip removal, heat reduction and lower wear rates on the auxiliary flank helps in reduction of surface roughness. Also surface roughness grows slowly with machining time under HPC condition.

iv. HPC takes away the major portion of heat and provides remarkable benefit in respect of controlling the thermal expansion of the job as a result decrease in dimensional deviation desirably with machining time.

ACKNOWLEDGEMENT

Research fund has been granted by Directorate of Advisory Extension and Research Services (DAERS) and facilities have been provided to carryout the experiment by the Department of Industrial and Production Engineering, BUET, Dhaka, Bangladesh. The authors are grateful to them.

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