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PERFORMANCE EVALUATION OF CARBIDE INSERTS IN TURNING C-60 STEEL AND 42CrMo4 STEEL UNDER HIGH-PRESSURE COOLANT (HPC) CONDITION

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ABSTRACT

High temperature during machining causes tool wear and premature failure of cutting tools, dimensional deviation and impairs the surface integrity of the product. In high speed machining, conventional cutting fluid fails to penetrate the chip-tool interface and thus cannot remove heat efficiently. Moreover, it has become problematic in terms of both employee health and environmental pollution. High pressure coolant (HPC) can solve the problems of traditional machining associated with convention coolant. This paper deals with the experimental investigation on the role of high pressure coolant on cutting temperature, tool wear, surface roughness and dimensional deviation in turning C-60 steel and 42CrMo4 steel by uncoated carbide inserts and a comparison between them. The encouraging results include significant reduction in tool wear rate, dimensional inaccuracy and surface roughness by high pressure coolant mainly through reduction in the cutting zone temperature and favorable change in the chip-tool and work-tool interaction.

Keywords: Turning, HPC, Tool Wear and Surface Roughness.

1. INTRODUCTION

The energy dissipated in machining operation is converted into heat which raises the temperature in the cutting zone. Excessive temperature adversely affects the strength, hardness and wear-resistance of the cutting tool which eventually leads to tool failure. Additionally, tool-wear increases with the increase of speed, feed and depth of cut, though their effects are different [1]. On the other hand, if the tool becomes dull or worn, heat is also generated when the tool tip rubs against the machined surface. So, it's a cyclical process. Increasing heat can cause dimensional inaccuracy and also cause distortion of the machine tool resulting poor dimensional control of the work piece. With the increase of cutting temperature and tool wear, surface roughness increases significantly. Cutting force is also increased with tool wear which results the increase of power consumption. All these problems increase further with the increase in hardness of the work material [2].

For reducing the cutting zone temperature through cooling and lubricating action cutting fluid (soluble oil) may be applied to the tool/work piece interface**.** In the high speed-feed machining, which inherently generated high cutting zone temperature, cutting fluid can't reach to the chip-tool interface to reduce the temperature [3]. Machining of ductile material in high speed produces long chips, where the length of chips affects the cutting temperature and thermo-chemical tool wear [4].

Cutting fluid systems are used in industry to deliver fluid to the cutting process, re-circulate fluid, separate chips and collect fluid mist. In flood cooling method, fluid is used in very large amount (6-10 l/hr). The cost associated with the use of cutting fluid is estimated to be about 16% to 20% of the total manufacturing costs [5, 6], where only 4% of the total manufacturing cost is associated with cutting tools [2]. So, in respect of costs, it is very important to reduce the amount of cutting fluid. Some conditions like machining steels by carbide tools, the use of coolant may increase tool wear [7].

Furthermore, the permissible exposure level (PEL) for metal working fluid aerosol concentration is 5 mg/m^3 as per the U.S. Occupational Safety and Health Administration [2] and is 0.5 mg/m^3 according to U.S. National Institute for Occupational Safety and Health [8]. The oil mist level in U.S. automotive parts manufacturing facilities has been estimated to be generally on the order of 20-90 mg/m^3 with the use of traditional flood cooling and lubrication [9]. This suggests an opportunity for improvement in coolant application during machining.

Moreover, for using cutting fluid environment becomes polluted. Because, for improving the lubricating performance Sulfur(S), Phosphorus(P), Chlorine(Cl) or other pressure additives are mixed with cutting fluid [10]. If the cutting fluids are not handled appropriately, it may damage soil and water resource, which can cause serious environment pollution. Additionally in the factory cutting fluid may cause skin and breathing problem of the operator [11]. So, dry machining is now considered as an environment friendly manufacturing [2]. But some times dry machining cannot show better performance if higher machining efficiency, better surface finish and other special cutting conditions are required. For these cases many special techniques can be used.

The cutting temperature can be reduced by selecting proper tool-work piece combination, improving the metallurgical property of the tool / work piece and proper selection of process parameters. Cubic Boron Nitride (CBN) can maintain its hardness and resistance to wear at elevated temperatures and has a low chemical reactivity to the chip/tool interface [12]. The CBN tool, if properly manufactured, provides less cutting forces, temperature and less tensile residual stresses [13]. Polycrystalline Cubic Boron Nitride (PCBN) also displays a unique combination of hardness, toughness and thermo-chemical stability, properties which are increasingly important in a cutting tool material to meet the demands of machining hard materials. But these tools are so much expensive and recommended to use in that case where other tool materials are not effective.

Coolant is supposed to cool and lubricate but it can only perform these functions at the point of chip formation if the coolant actually reaches the cutting zone. When coolant is turned to steam or otherwise fails to reach the target, it does not perform its two essential functions (cooling and lubricating). This problem increases at the time of high speed machining [16]. If the coolant is applied at the cutting zone through a high speed nozzle, it could reduce the contact length and co-efficient of friction at chip-tool interface then cutting force and temperature may be reduced and tool life can be increased [17, 18]. High-pressure is often the solution to get the coolant to the target so it can cool, lubricate, and sometimes perform its third function- chip breaking that do not break neatly with ordinary machining processes [19].

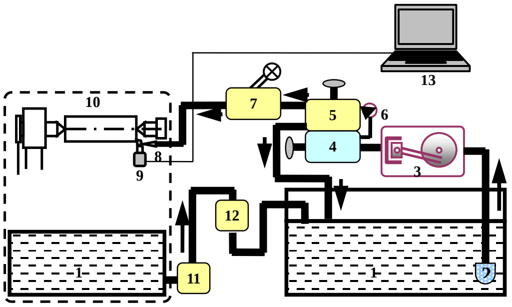
In drilling operations when temperature is increased a large amount of tool wear appears at the drill bit. Such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the surface integrity of the product; either it affects roundness of the hole or chip shape and color of chip. High-pressure coolant has reduced temperature as well as improving roundness and also provides lubrication in the tool tip and surface interface [20].

In Grinding operation material is generally removed by shearing and ploughing in the form of micro sized chips by the abrasive grits of the grinding wheel. As a result, high temperature is produced in the grinding zone due to large negative rake and high cutting speed of the grinding wheel. High-pressure coolant jet effectively reduces cutting zone temperature entering into chip tool interface maintaining a good surface integrity [21].

The present work intends to clarify some points relating temperature, tool wear and surface roughness when turning C-60 steel and 42CrMo4 steel at high cutting speeds and feed rates.

2. EXPERIMENTAL INVESTIGATION

The experiment was carried out on a center lathe of 10 hp and maximum spindle speed of 1400 rpm. The schematic view of the experimental set-up is shown in Fig.1. The tool holder provided negative 6° side and back rake angles and 6° side cutting-edge and end cutting-edge angles. The ranges of the cutting speed (V) and feed rate (f) were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut, being less significant parameter, was kept fixed (1.0 mm for temperature and 1.5 mm for wear). The experimental conditions are given in Table-1.



1 Coolant tank
2 Foot valve
3 High-pressure pump
4 Flow control valve
5 Relief valve
6 Pressure gauge
7 Direction control valve
8 Nozzle
9 Dynamometer
10 Machine tool
11 Supply pump
12 Filter
13 Computer

Fig 1. Schematic view of experimental set-up

Table 1: Experimental conditions

Machine tool	: Lathe, 10 hp (China)
Work material	: C-60 steel and 42CrMo4 steel
Cutting tool	: SNMG 120408 and SNMM 120408
Process parameters	
Cutting speed, V	: 93,133, 186, 193 and 266 m/min
Feed rate, f	: 0.10, 0.14, 0.18 and 0.22 mm/rev
Depth of cut, d	: 1.00 mm and 1.50 mm
HPC supply	: 80 bar with a flow rate of 6.0 l/min
Environment	: Dry and HPC (VG 68 cutting oil)

High-pressure coolant jet impinged at the chip-tool interface zone for removing temperature through the nozzle at an angle from a suitable distance. The cutting fluid needs to be drawn at high pressure from the coolant tank and impinged at high speed through the nozzle. Considering the conditions required for the present research work and uninterrupted supply of coolant at pressure around 80 bar over a reasonably long cut, a coolant tank has been designed, fabricated and used. The high-pressure coolant jet is directed in such a way that it reaches at the rake and flank surface and to protect auxiliary flank to enable better dimensional accuracy.

The application of high-pressure coolant jet is expected to affect the various machinability characteristics mainly by reducing the cutting temperature. Simple but a reliable tool–work thermocouple technique with proper calibration was used to measure the average cutting temperature under both dry and high-pressure coolant condition.

The cutting insert was withdrawn at regular intervals to study the pattern and extent of wear on main and auxiliary flanks for all the trials. The average width of the principal flank wear, VB and auxiliary flank wear, VS were measured using in inverted metallurgical microscope (Carl zeiss) fitted with micrometer of least count 1.0 µm. The surface roughness was monitored by a Talysurf (Surtronic 3^+, Rank Taylor Hobson) using a sampling length of 0.8mm. At the end of full cut, the cutting inserts were inspected under scanning electron microscope (Philips XL 30, Belgium).

3. RESULTS AND DISCUSSION

The average cutting temperature measured by tool-work thermocouple technique during turning at different cutting speeds and feeds under both dry and high-pressure coolant (HPC) condition is shown in Fig.2 and Fig.3. It shows how and to what extent average cutting temperature has decreased due to high-pressure coolant application under the different experimental conditions. With the increase in V and f, the average temperature increased as usual, even under HPC condition, due to increase in energy input. It can clearly be observed from Fig.2 and Fig.3 that HPC is able to reduce average cutting temperature for both C-60 steel and 42CrMo4 steel compared to dry machining. At V ≤100 m/min and all feed range, reduction in cutting temperature more than moderate speed used (V =100-200 m/min and all feed range). At higher speed (V >200m/min) and all feed range reduction in average temperature is minimum

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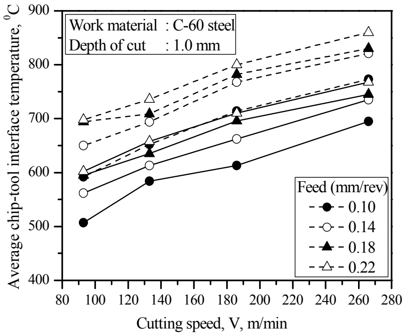

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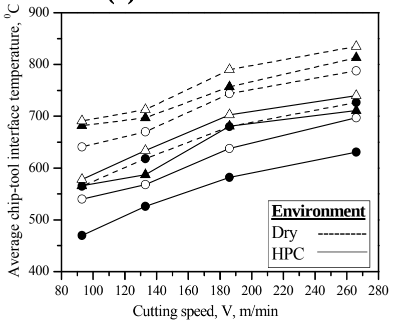

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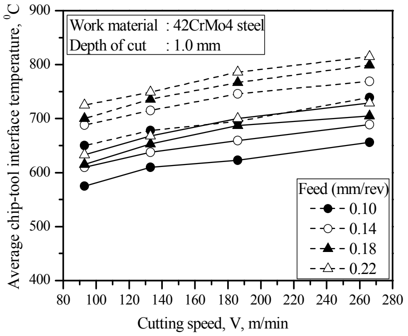
Fig 2. Variation in temperature in turning C-60 steel

It is evident from Fig.2 and Fig.3 that as the cutting speed and feed rate increases, the rate of reduction in average cutting temperature decreases. It may be for the reason that, with the increase in V and f, the bulk contact of the chips with the tool did not allow significant entry of high-pressure coolant jet. Only possible reduction in the chip-tool contact length by the high-pressure coolant jet, particularly that which comes along the auxiliary cutting edge, could reduce the temperature to some extent particularly when the chip velocity was high due to higher V and f, this amount of reduction in average cutting temperature is quite significant in pertaining tool life and surface finish.



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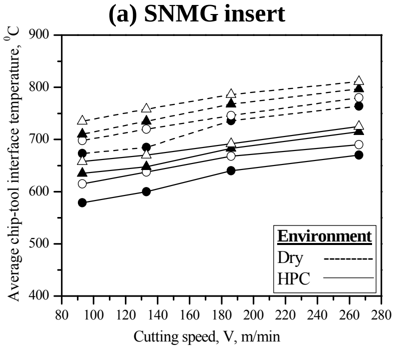

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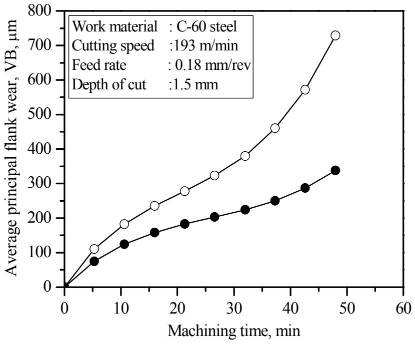
Fig 3. Variation in temperature in turning 42CrMo4 steel

Productivity and economy of manufacturing by machining are significantly affected by life of the cutting tools. Cutting tools may fail by brittle fracturing, plastic deformation or gradual wear. 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 due to continuous interaction and rubbing with the chips and the work surfaces respectively. Among the aforesaid wears, the principal flank wear is the most important because it raises the cutting forces and the related problems. 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 0.3 mm. Therefore, attempts should be made to reduce the rate of growth of principal flank wear (VB) in all possible ways without much sacrifice in MRR. The cutting insert was withdrawn at regular intervals to study the pattern and extent of wear on main and auxiliary flanks under both dry and high-pressure coolant conditions.



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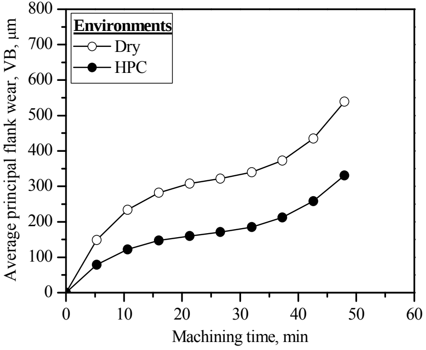

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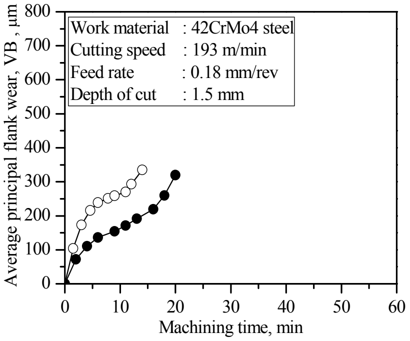
Fig 4. Growth of VB during turning C-60 steel



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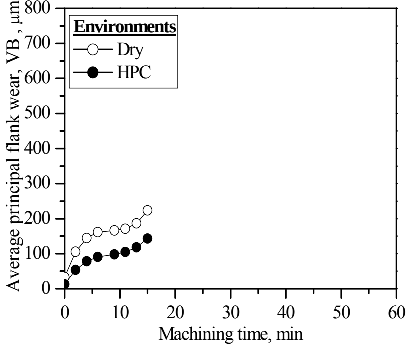

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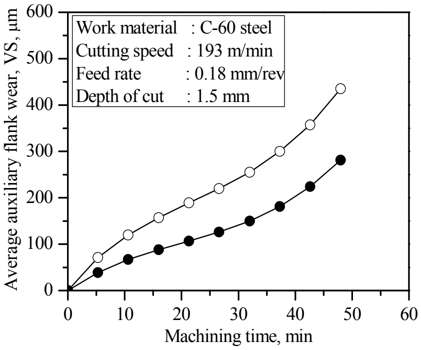
Fig 5. Growth of VB during turning 42CrMo4 steel

The growth of principal flank wear (VB) with progress of machining was recorded during turning at moderately high cutting speed, feed and depth of cut under both dry and high-pressure coolant condition have been shown in Fig.4 and Fig.5. Fig.4 and Fig.5 clearly show that flank wear (VB) particularly its rate of growth, decreases substantially by high-pressure coolant jet. The cause behind reduction in VB observed may reasonably be attributed to reduction in the flank temperature by high-pressure coolant jet impinged along the auxiliary cutting edge, which helps in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion types of wear which are highly sensitive to temperature. Because of such reduction in rate of growth of flank wear, the tool life would be much higher if high-pressure coolant is properly applied.



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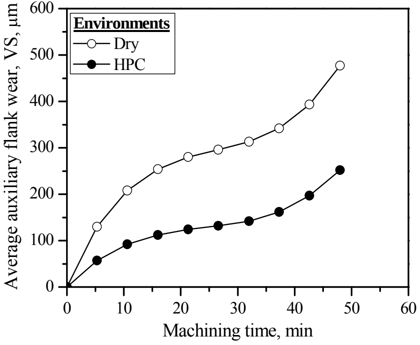

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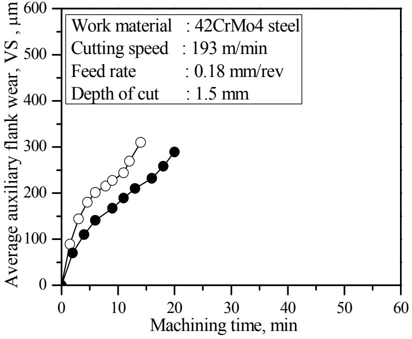
Fig 6. Growth of VS during turning C-60 steel

The auxiliary flank wear affects dimensional accuracy and surface finish has also been recorded at regular intervals of machining under all the conditions undertaken. The growth of average auxiliary flank wear (VS) with machining time under both dry and high-pressure coolant conditions have been shown in Fig.6 and Fig.7. It appears from Fig.6 and Fig.7 that auxiliary flank wear (VS) has also decreased significantly due to application of HPC jet.

The flank wear occurred quite fast due to rapid attrition wear followed by adhesion and diffusion in addition to usual abrasion particularly at the tool tip where stresses and temperature are high. Rapid start of flank wear causes more intimate contact at the work-tool interface and initiates severe rubbing which again aggravates flank wear further. Flank wear grow so fast in turning by carbide insert that notching and grooving type wear do not appear separately.

The SEM views of the worn out insert after being used under both dry and high-pressure coolant conditions are shown in Fig.8 and Fig.9. Under all the environments, abrasive scratch marks appeared in the flanks. There have also been some indications of adhesive wear especially under dry condition, which produced unfavorable chips as compared to high pressure coolant condition that produced favorable chips.



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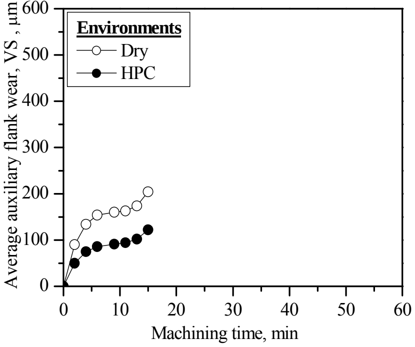

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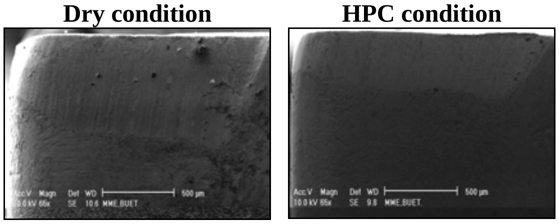
Fig 7. Growth of VS during turning 42CrMo4 steel

But it is clearly evident from Fig.8 and Fig.9 that high-pressure coolant jet machining caused lesser wear than that produced by dry machining. Such reduction in wear is seemingly indebted to reduction of the cutting temperature sensitive wear phenomenon like diffusion and adhesion enabled by direct and indirect cooling by high-pressure coolant jet.



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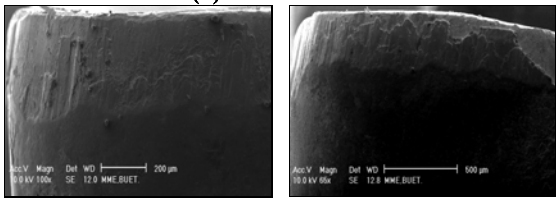

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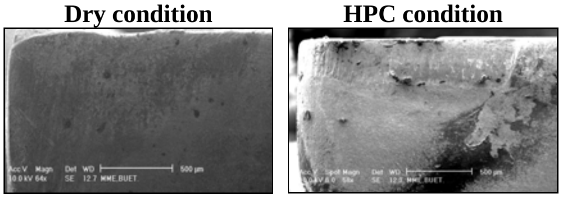
Fig 8. SEM views of worn out insert during turning C-60 steel

In machining research, a cutting tool is generally said to have failed when its VB reaches a specific value, mostly 300 µm. The life of the turning insert is generally evaluated on the basis of this limiting value of average flank wear, VB. Considering VB=300 µm as tool life criteria, the tool life values obtained in machining C-60 steel for both the inserts under both conditions have been represented in three dimensional wire frame graph in Fig.10. Fig.10 shows that the tool life decreases with the increase of V and f as usual under all the environments undertaken. Tool life improved to some extent particularly when this material was machined at relatively lower V and f but high-pressure coolant jet enhanced tool life more pronouncedly though the benefit gradually decreased with the increase in cutting velocity and feed rate. The high-pressure coolant system increased tool life by approximately twice when turning C-60 steel by the inserts.



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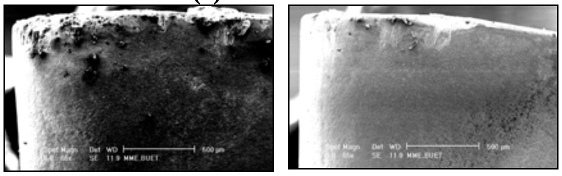

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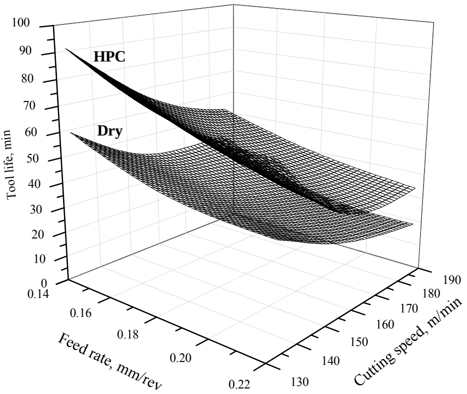
Fig 9. SEM views of worn out insert during turning 42CrMo4 steel



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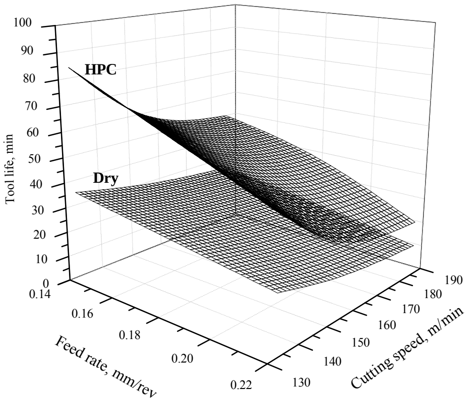

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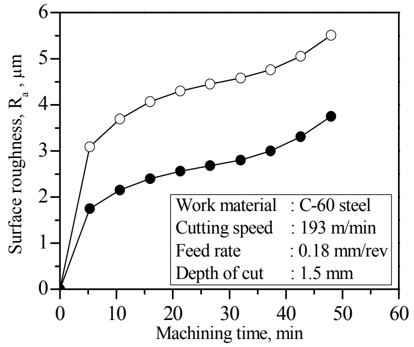
Fig 10. Effect of dry and HPC on tool life during machining C-60 steel

The nature and extent of surface roughness in the longitudinal direction of the turned job depend mainly upon the geometry and condition of the auxiliary cutting edge including a part of the rounded nose. The value of surface roughness increases sharply with the increase in feed and decreases with increase in V. Built-up edge formation and vibration worsen the surface further.

The resulting surface finishes under both dry and high-pressure coolant conditions are shown in Fig.11 and Fig.12. As high-pressure coolant jet reduced average auxiliary flank wear (VS) on auxiliary cutting edge, surface roughness also grew very slowly under high-pressure coolant condition.

The results shown in Fig.11 and Fig.12 indicate that surface roughness increased substantially with the increase in feed when machined by both the tools and under both the environments. This can be attributed mainly to the roughness caused by the feed marks as explained earlier. It is also noted that surface roughness decreased to some extent with the increase in V possibly due to smoothening of the nose profile by adhesion and diffusion types wear. However, incase of both the tools surface roughness decreased to some extent when the job was machined under HPC. This can be attributed to reduction in VS due to retention of tool hardness through reduction in temperature by the HPC jet.



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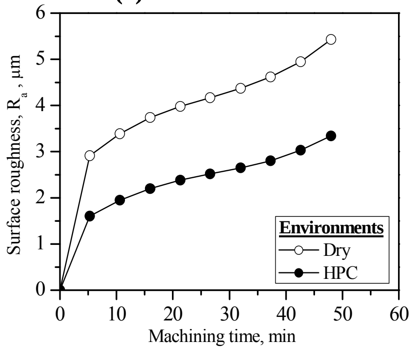

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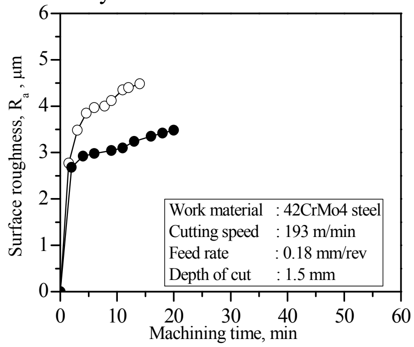
Fig 11. Surface roughness (R_a) developed with progress of machining of C-60 steel

High pressure coolant provided remarkable benefit in respect of controlling the increase in diameter of the finished job with machining time as can be seen in Fig.13 and Fig.14. 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. With the increase in temperature the rate of growth of auxiliary flank wear and thermal expansion of the job will increase. HPC takes away the major portion of heat and reduces the temperature resulting decrease in dimensional deviation desirably.



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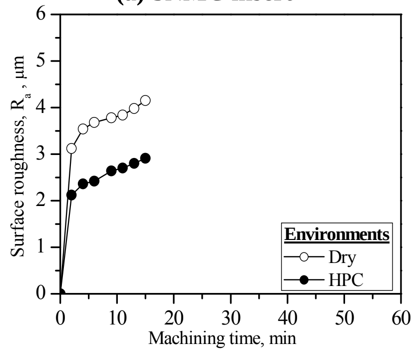

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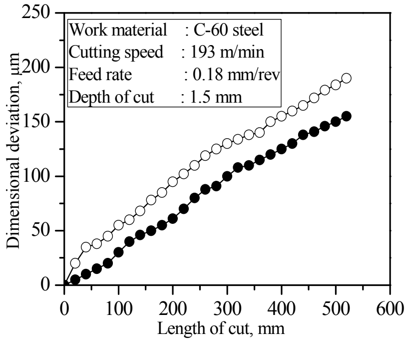
Fig 12. Surface roughness (R_a) developed with progress of machining of 42CrMo4 steel



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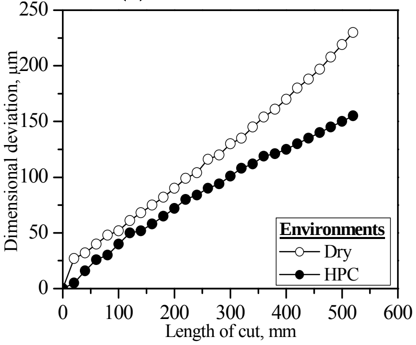

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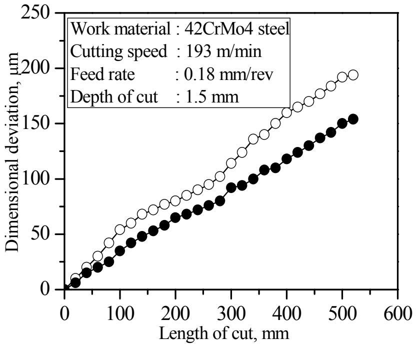
Fig 13. Dimensional deviation observed after one full pass turning of C-60 steel



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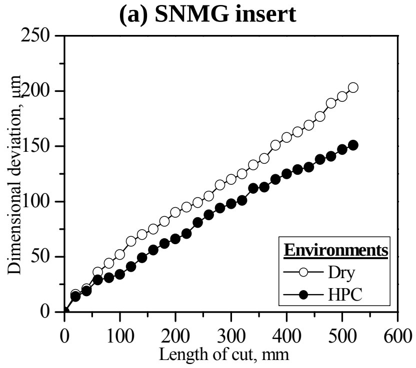

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Fig 14. Dimensional deviation observed after one full pass turning of 42CrMo4 steel

4. CONCLUSIONS

i. The cutting performance of HPC jet assisted machining is better than that of dry machining.
ii. HPC provides the benefits mainly by substantial reducing the cutting temperature, which improves the chip-tool interaction and maintains sharpness of the cutting edges.
iii. HPC machining of steel caused lesser tool wear in comparison to dry machining and increased tool life.
iv. HPC cooling by insoluble oil jet provided better surface finish and higher dimensional accuracy as compared to dry machining.

5. ACKNOWLEDGEMENTS

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