



# THE INFLUENCE OF HIGH PRESSURE COOLANT ON TEMPERATURE TOOL WEAR AND SURFACE FINISH IN TURNING 17CrNiMo6 AND 42CrMo4 STEELS

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## ABSTRACT

Machining of steel and other hard materials under high speed-feed condition requires instant heat transfer from the cutting interface of the tool and the work material where the intensity of cutting temperature is the maximum to avoid surface distortion and to improve tool life. Conventional cooling fails to control the cutting temperature and to maintain the product quality. Moreover it is hazardous for human being and a major source of pollution in the industries. High pressure and high velocity coolant may provide the best control to reduce cutting temperature and tool wear as well as to increase tool life. This paper deals with an experimental investigation of the effect of high-pressure coolant on temperature, tool wear and surface roughness in machining of 17CrNiMo6 and 42CrMo4 steels using uncoated carbide tools and comparing them under dry cut condition as well as the materials themselves. The inspiring experimental results include the reduction of cutting temperature and tool wear and improvement of surface finish with the use of high-pressure coolant. But increasing hardness increases cutting temperature and tool wear rate.

**Keywords:** high-pressure coolant, cutting temperature, tool wear and surface finish.

## INTRODUCTION

A finished product with desired shape, size and accuracy is manufactured usually from a piece of raw material. During machining, a tool penetrates into the work piece because of the relative motion between the tool and the work piece and 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.

In industries, a flood of conventional coolant is usually applied from the over head position to remove the heat generated at the cutting zone. During machining [1], 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. For this reason, conventional coolant is often used on the cutting tool for bulk cooling and to prevent overheating. However, the main problem [2] with conventional coolant is that it does not reach the real cutting area i.e. chip tool interface where the maximum temperature attains. The extensive heat generated evaporates the coolant before it can reach the cutting area and makes a semi conductive vapor barrier and consequently prevents heat conduction. The high cutting forces generated during machining will 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 part of the world. Cutting forces and temperature were found to reduce while machining steel with tribologically modified carbide inserts [3]. Application of CO<sub>2</sub> in the form of liquid jet at high pressure also enabled [4] some reduction in cutting forces. 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. Also accelerated notch wear on the principal flank of the carbide insert was 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 [9, 10, 11], which has shown as the decrease in heat and cutting forces generated. Mazurkiewicz [11] reported that a coolant jet applied to the cutting zone at



high-pressure through a nozzle could reduce the contact length and coefficient of friction at chip-tool interface and thus could reduce cutting forces and increase tool life to some extent. High-pressure coolant injection technique is not only provided a reduction in cutting forces and temperature but also reduced the consumption of cutting fluid by 50% [13, 14].

The review of the literature suggests that high-pressure coolant 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 and surface roughness and compares the effectiveness of high-pressure coolant with that of dry machining.

## EXPERIMENTAL INVESTIGATION

Plain turning of 17CrNiMo6 steel ( $\Phi 200 \times 520$  mm) and 42CrMo4 ( $\Phi 220 \times 520$  mm) steel rod of common use were carried out in a lathe (10 hp, China) at different cutting velocities ( $V_c$ ) and feeds ( $S_o$ ) under both dry and high-pressure coolant conditions. The schematic view of the experimental set-up used for the present purpose is shown in Figure-1. The machinability indices of the work materials of different hardness have been investigated especially for cutting temperature, tool wear and surface roughness to study the role of high-pressure coolant on materials and on their hardness. The process parameters for this experiment are given in Table-1. Cutting velocity ( $V_c$ ) and feed rate ( $S_o$ ) ranges were selected as per the recommendation of tool manufacturer considering high material removal rate. Depth of cut is less significant as it only changes the magnitude of cutting forces, was kept constant to 1.5 mm all through the experimental domain of tool wear.

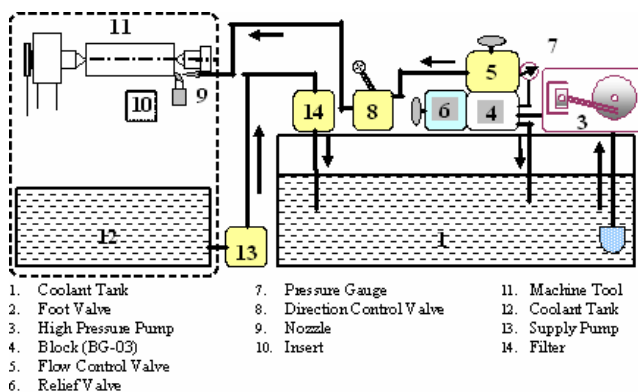


Figure-1. Schematic view of the experimental set-up.

Considering the force exerted on the edge of cutting tool during machining a suitable cutting speed and feed (193 m/min, 0.18 mm/rev) was selected for tool wear

monitoring. Pump pressurizes the coolant at a pressure of 80 bars with a flow rate 6 l/min. Taking into account the jet pattern and covering the entire cutting area by issuing jet, the nozzle diameter was selected as 0.5 mm. The high velocity stream of high-pressure coolant jet was impinged along the auxiliary cutting edge of the insert, so that the coolant reaches as close to the chip-tool and the work-tool interfaces as possible and effectively cools the tool and the work material at the hot cutting zone.

Table-1. Experimental conditions.

<b>Machine tool</b>	: Lathe (China), 10 hp
<b>Work specimen</b>	
Materials	: • 17CrNiMo6 steel • 42CrMo4 steel
BHN	: • 201 for 17CrNiMo6 steel • 252 for 42CrMo4 steel
<b>Cutting insert</b>	: • SNMG insert, Sandvik • SNMM insert, Sandvik
<b>Tool holder</b>	: PSBNR 2525 M12, Sandvik
<b>Tool geometry</b>	: -6°, -6°, 6°, 15°, 75°, 0.8 mm
<b>Process parameters</b>	
Cutting velocity	: 93, 133, 186, 266 and 193 m/min
Feed rate	: 0.10, 0.14, 0.18 and 0.22 mm/rev
Depth of cut	: 1.0 mm and 1.50 mm
<b>High pressure coolant</b>	: 80 bar, Coolant: 6.0 l/h through external nozzle
<b>Environments</b>	: Dry and high-pressure coolant (HPC) condition

The average cutting temperature was measured by simple but reliable tool-work thermocouple technique with proper calibration [14]. Machining was interrupted at regular interval and the insert was unclamped to measure the width of wear land on the principal and auxiliary flank. Tool wear was monitored under optical microscope (Carl zeiss, Germany) fitted with micrometer of least count 10  $\mu$ m. Surface roughness was measured at every interruption along the longitudinal direction of the turned job with the help of a Talysurf roughness checker (Surtronic 3<sup>+</sup>, Taylor rank Hobson, UK). As per ISO standard tool rejection criteria was selected as the growth of wear  $V_B = 300 \mu$ m on its principal flank. When the tool wear reaches to its limiting value or unexpectedly wear out rapidly, it was inspected under scanning electron microscope (Philips XL30) to study the wear mechanism.

## RESULTS AND DISCUSSIONS

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. 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 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 high-pressure coolant on average chip-tool interface temperature ( $\theta$ ) at different  $V_c$  and  $S_o$  has been shown in Figure-2 and Figure-3. It is clear from Figure-2 and Figure-3 that during machining at lower  $V_c$  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 high-pressure coolant is easily dragged in the elastic contact zone. With an increase in  $V_c$  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 is less in comparison with lower speed. High-pressure cooling effect also improved to some extent with the decrease in feed particularly at lower cutting velocity. At lower chip velocity, the thinner chips are pushed up by the high-pressure coolant jet coming from opposite direction of chip flow and enable it to come closer to the hot chip-tool contact zone to remove heat more effectively. Lifting up the chips with high-pressure coolant also facilitates chip breakability which indicates a decrease in shear angle. With an increase in feed curl radius of the thick chip is increased. For this, plastic contact length is increased and high-pressure coolant jet becomes less effective. At high velocity, 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 high-pressure cooling condition at high cutting velocity. 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.

Usually cutting temperature is increased with the increase in speed and feed. But some anomalies in temperature are observed during machining 17CrNiMo6 with SNMG insert. Temperature is more at a feed rate of 0.10 and 0.18 mm/rev than feed rate 0.14 and 0.22 mm/rev under the range of cutting velocity undertaken and under both the condition. Higher temperature was recorded during cutting harder material with SNMG insert. It is evident from Figure-2 and Figure-3 that temperature is more as compared to 17CrNiMo6 steel with 42CrMo4 steel while machining with SNMG insert. But effect of hardness is not evident while machining the steels with SNMM insert. The percent reduction of cutting temperature for both the insert and materials is shown in Table-2. It is evident from the table that with the increase in feed the rate of reduction in temperature decreases.

**Table-2.** Percent reduction of cutting temperature.

Cutting	Feed	Work material			
		17CrNiMo6 steel		42CrMo4 steel	
		Cutting insert		Cutting insert	
		SNMG	SNMM	SNMG	SNMM
93	0.10	18	19	24	25
	0.14	17	18	24	23
	0.18	18	17	19	20
	0.22	17	16	14	15
133	0.10	17	19	21	24
	0.14	15	19	20	20
	0.18	16	16	14	19
	0.22	12	15	11	10
186	0.10	13	15	19	21
	0.14	11	16	17	18
	0.18	14	15	13	12
	0.22	11	10	9	10
266	0.10	14	16	16	17
	0.14	14	14	13	16
	0.18	12	13	9	8
	0.22	9	11	8	7

Under usual cutting conditions the cutting edge of a form stable cutting tool is worn 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. 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 ( $V_B$ ) of its principal flank wear reaches a limiting value, like 300  $\mu\text{m}$ . 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 ( $V_B$ ) without sacrificing metal removal rate.

The growth of average principal flank wear ( $V_B$ ) with machining time at high cutting velocity (193 m/min) and depth of cut (1.5 mm) by both the insert for both the material under dry and high-pressure coolant conditions have been shown in Figure-4 and Figure-5, respectively. It is observed that while dry cutting principal flank wear is more than that of high-pressure coolant condition.



Tool wear reduces due to substantial reduction in cutting zone as well as flank temperature and lubrication in the interface by high-pressure coolant 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. While dry cutting 42CrMo4 steel using SNMG insert, severe spark out is observed and the insert wear out rapidly in the last pass. Under high pressure coolant condition SNMG insert also wear out at its last cut. Before the appearance of spark, the wear data taken is plotted and shown in Figure-5.

Auxiliary flank wear ( $V_S$ ), 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 and Figure-7 that auxiliary flank wear ( $V_S$ ) for both SNMG and SNMM insert have also decreased sizably due to high-pressure jet cooling. Oil film lubrication reduces the frictional heat generation as well as abrasion wear.

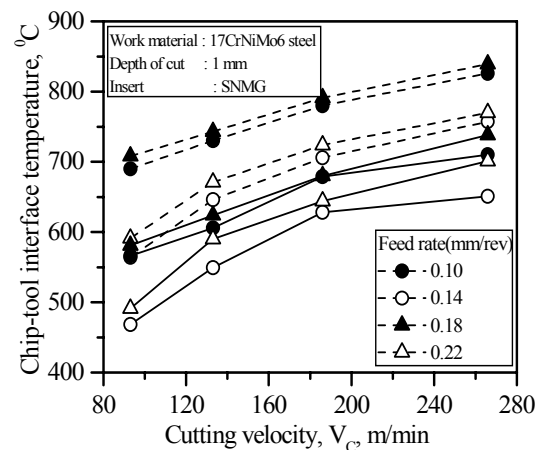
During metal cutting 33HRC is called transition hardness [15] because the effective zone under high pressure and dry cut for reducing flank wear is clearly mapped out from this hardness. Both the work materials with different hardness used in the experiment show the hardness below transition hardness. No significant improvement is found on hardness after employing high pressure coolant.

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. The SEM views of principal flank of the worn out SNMG and SNMM inserts after being machined 17CrNiMo6 steel about 22 minutes and 20 minute respectively under dry and high- pressure coolant conditions have been shown in Figure-8 and Figure-9, respectively. Abrasive scratch marks appeared in the flanks in almost all the trials. No notch wears at the flank surfaces were found in insert under both dry and high-pressure coolant conditions. Effective temperature control and oil film lubrication by high-pressure coolant reduced oxidation completely. It has enabled the elimination in the principal and auxiliary notch wear.

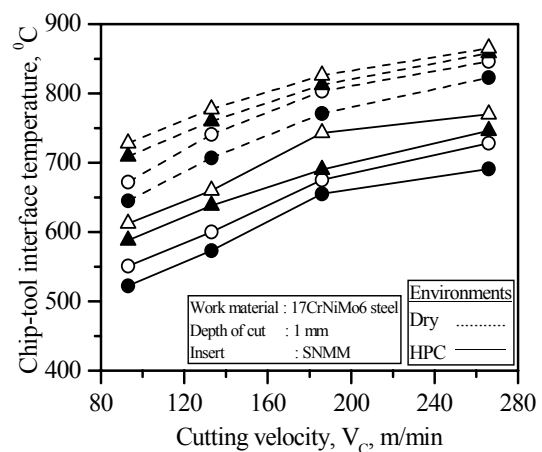
The SEM views of principal flank of the worn out SNMG insert after being machined 42CrMo4 steel about 14 minutes and 20 minute under dry and high- pressure coolant conditions have been shown in Figure-10. Tool edge wears out as soon as the last pass starts followed by severe sparking. Tool is withdrawn quickly and examined under SEM. Almost gradual wear was found before the appearance of spark and consequential blunting the cutting edge. Principal flank of the worn out SNMM inserts after 10.5 minutes and 13 minute under dry and high-pressure coolant conditions have been shown in Figure-11. Although cooling occurs by film boiling at the depth of cut area, the other heat sources increases the temperature,

causing severe thermal shock, and hence micro chipping occurs on the flank of SNMM insert.

Figure-12 and Figure-13 show the variation in surface roughness with progress of machining under dry and high- pressure coolant conditions. As high- pressure coolant reduced average auxiliary flank wear preventing the bulging of auxiliary flank, preventing the formation of built-up edge or removing instantaneously growing built-up edge, cooling the job effectively, surface roughness grew very slowly under high-pressure coolant conditions. It appears from the figures that surface roughness grows quite faster under dry condition. Softening of the metal in absence of coolant, increase surface roughness under dry condition. Increase in hardness of the work material also decreases surface roughness.



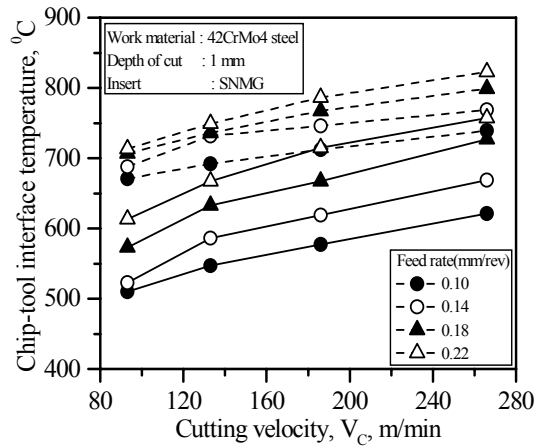
(a) SNMG 120408-TTS



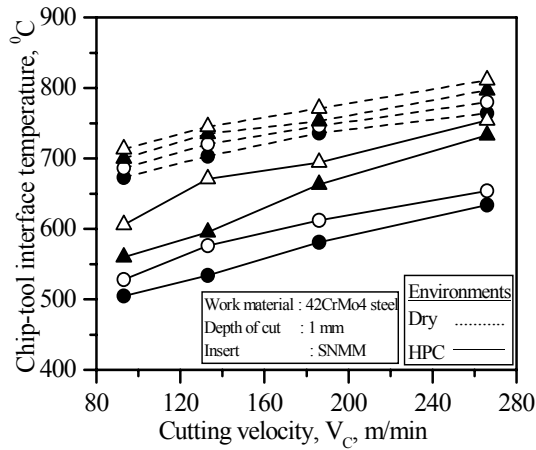
(b) SNMM 120408-TTS

**Figure-2.** Variation in temperature with that of  $V_c$  and  $S_0$  in turning 17CrNiMo6 steel by (a) SNMG and (b) SNMM inserts under different environments.



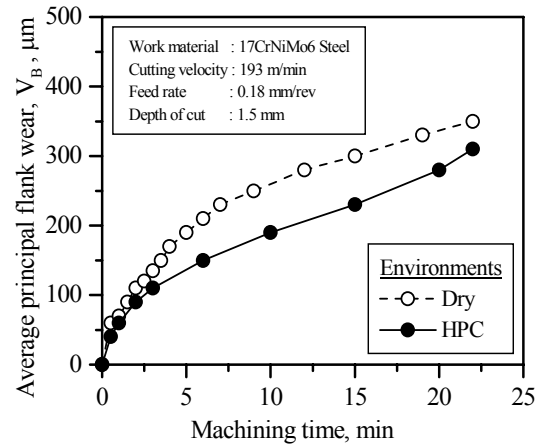


(a) SNMG 120408-TTS

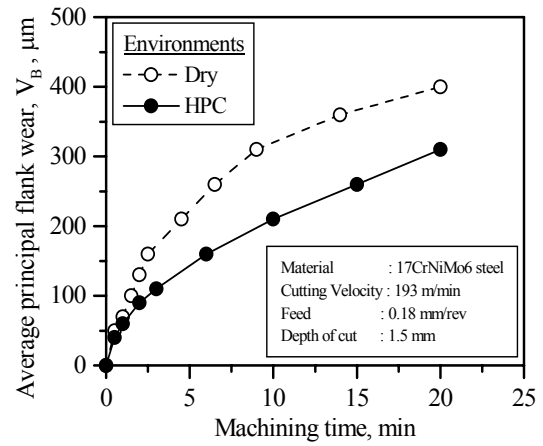


(b) SNMM 120408-TTS

**Figure-3.** Variation in temperature with that of  $V_c$  and  $S_o$  in turning 42CrMo4 steel by (a) SNMG and (b) SNMM inserts under different environments.

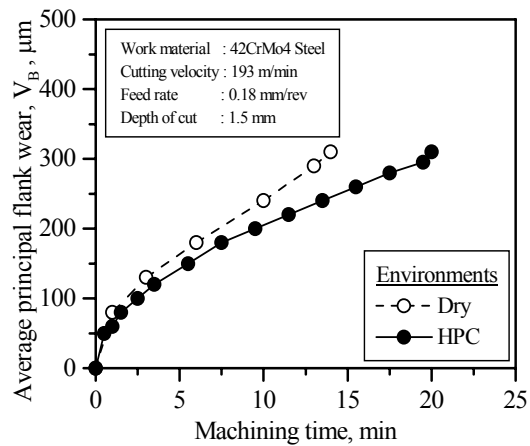


(a) SNMG 120408-TTS

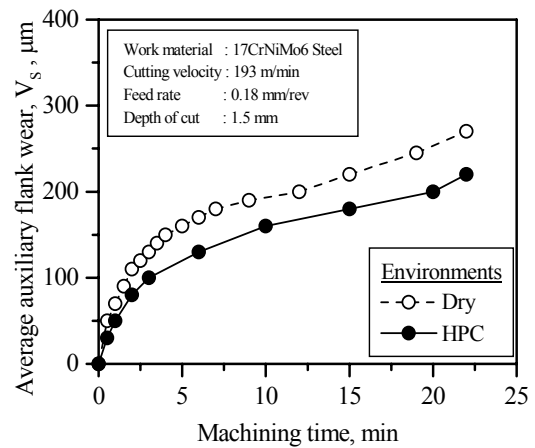


(b) SNMM 120408-TTS

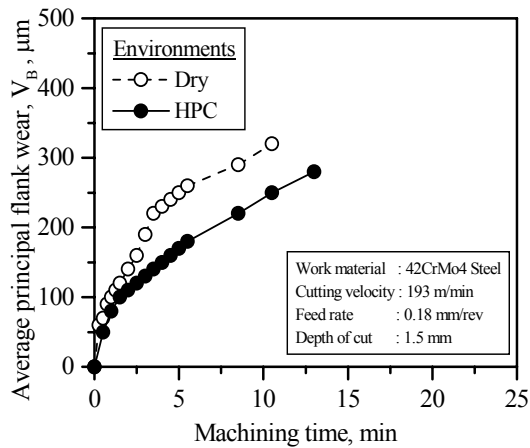
**Figure-4.** Growth of  $V_B$  with machining time in turning 17CrNiMo6 steel by (a) SNMG and (b) SNMM inserts under different environments.



(a) SNMG 120408-TTS

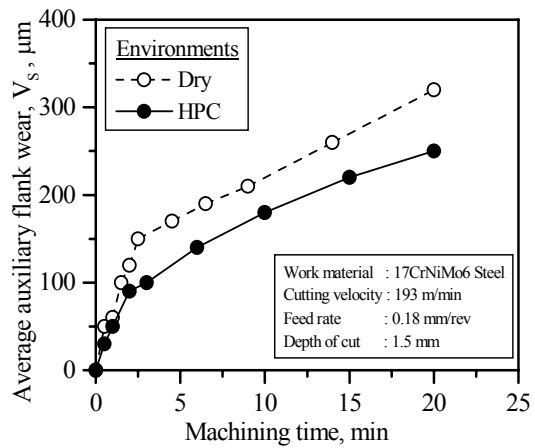


(a) SNMG 120408-TTS



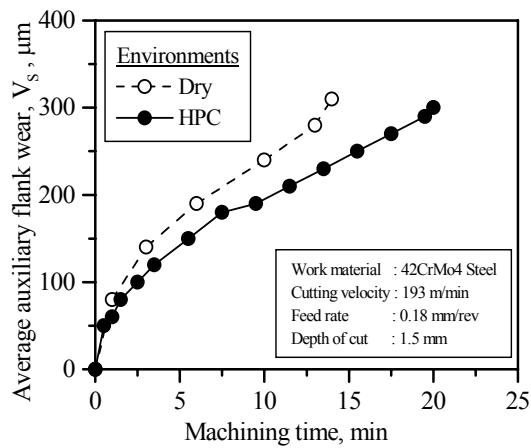
(b) SNMM 120408-TTS

**Figure-5.** Growth of  $V_B$  with machining time in turning 42CrMo4 steel by (a) SNMG and (b) SNMM inserts under different environments

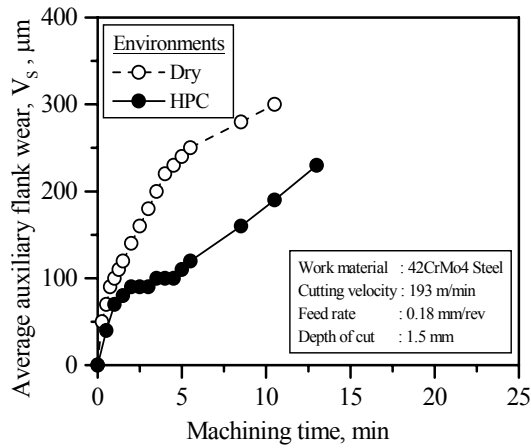


(b) SNMM 120408-TTS

**Figure-6.** Growth of  $V_S$  with machining time in turning 17CrNiMo6 steel by (a) SNMG and (b) SNMM inserts under different environments.

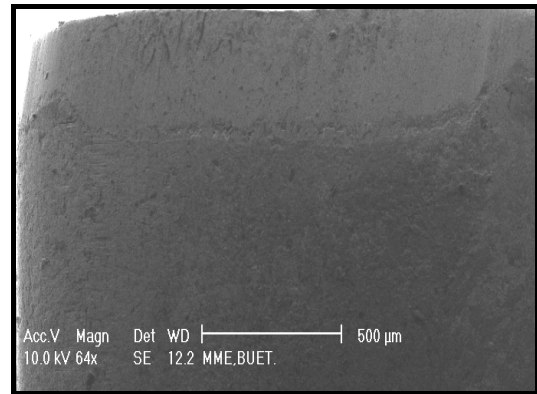


(a) SNMG 120408-TTS

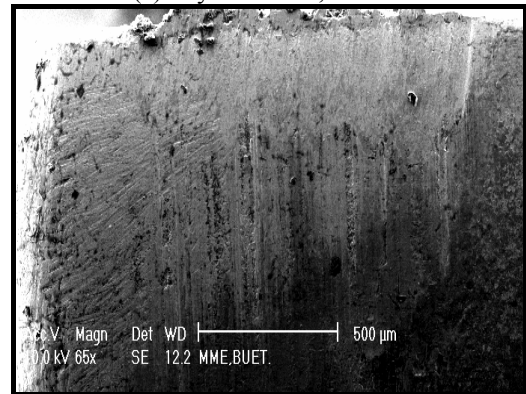


(b) SNMM 120408-TTS

**Figutr-7.** Growth of  $V_s$  with machining time in turning 42CrMo4 steel by (a) SNMG and (b) SNMM inserts under different environments.

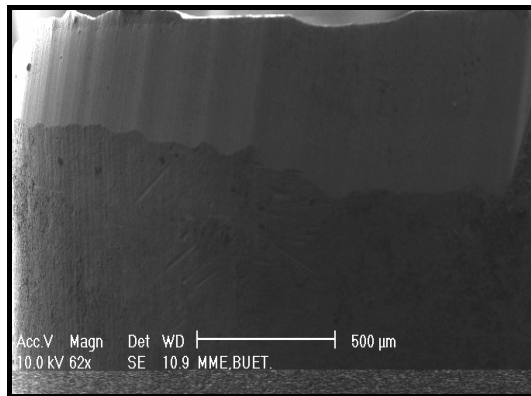


(a) Dry condition, 22 min

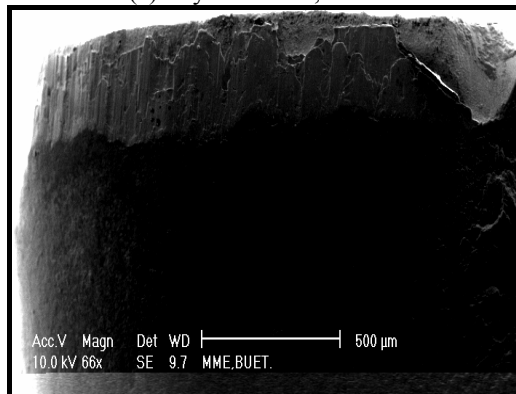


(b) High-pressure coolant condition, 22 min

**Figure-8.** SEM views of principal flank of worn out tip of SNMG insert after machining 17CrNiMo6 steel under different environments.

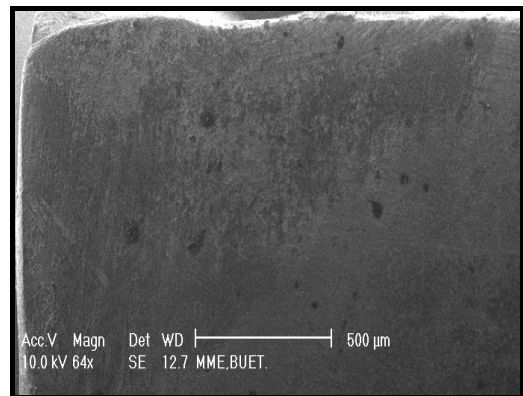


(a) Dry condition, 20 min

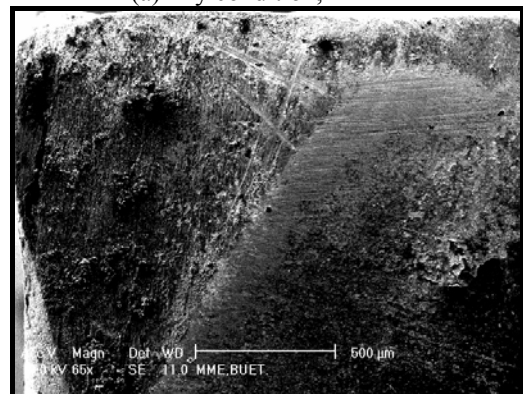


(b) HPC condition, 20 min

**Figure-9.** SEM views of principal flank of worn out tip of SNMM insert after machining 17CrNiMo6 steel under different environments.



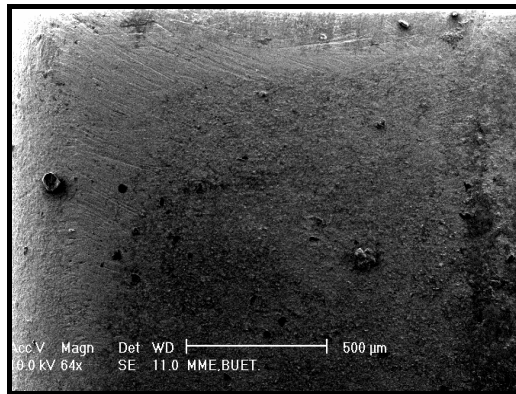
(a) Dry condition, 14 min



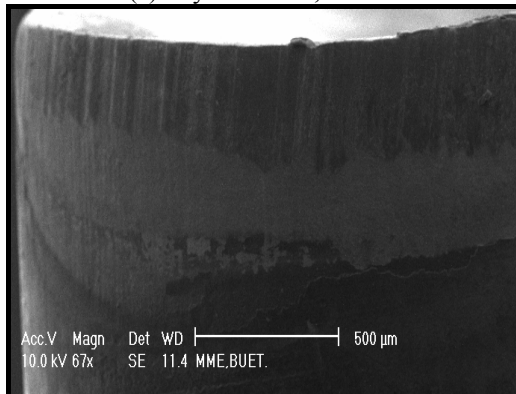
(b) High-pressure coolant condition, 20 min

**Figure-10.** SEM views of principal flank of worn out tip of SNMG insert after machining 42CrMo4 steel under different environments.



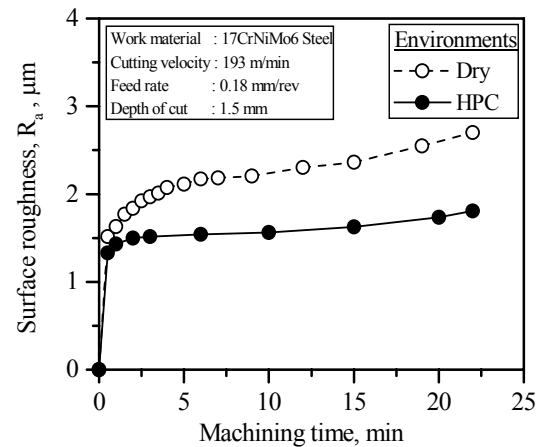


(a) Dry condition, 10 min

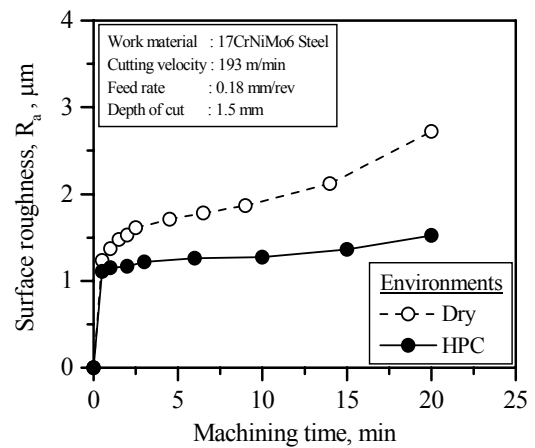


(b) HPC condition, 13 min

**Figure-11.** SEM views of principal flank of worn out tip of SNMM insert after machining 42CrMo4 steel under different environments.

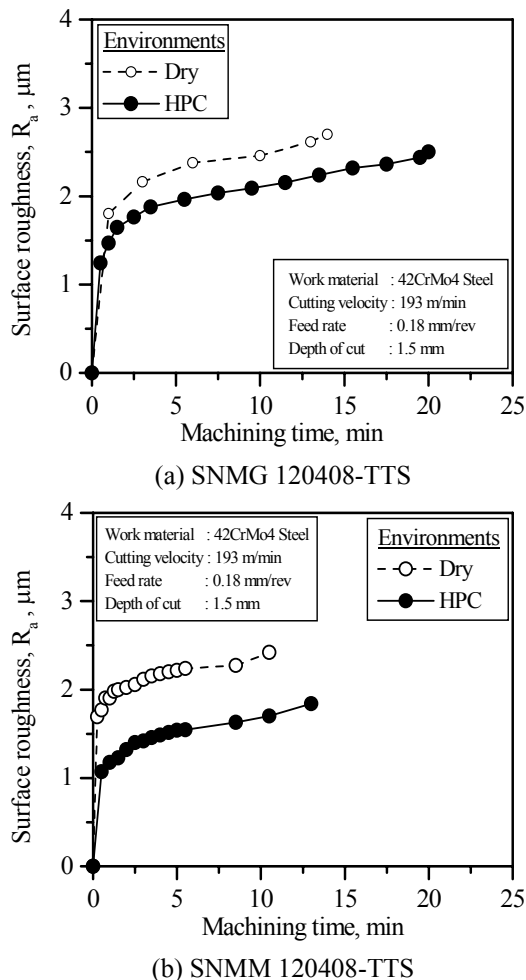


(a) SNMG 120408-TTS



(b) SNMM 120408-TTS

**Figure-12.** Surface roughness ( $R_a$ ) developed with progress of machining of 17CrNiMo6 steel by (a) SNMG and (b) SNMM inserts under different environments.



**Figure-13.** Surface roughness ( $R_a$ ) developed with progress of machining of 42CrMo4 steel by (a) SNMG and (b) SNMM inserts under different environments

## CONCLUSIONS

- i Application of high-pressure coolant along auxiliary cutting edge over the rake face of the tool forms a cushion layer by oil film that reduces friction at the tool-chip interface. Oil film prevents intimate contact between the tool and chip at the interface. Oil enters into the interface and significant reduction of temperature occurs while turning;
- ii The performance of high-pressure coolant machining is advantageous over dry machining because high-pressure cooling maintains the sharp cutting edge for prolonged time of machining. High-pressure coolant enables reduction of cutting temperature up to 25% depending upon process parameter;
- iii High-pressure coolant enables considerable reduction in the cutting zone temperature and favorable change in the chip-tool and work-tool interactions, which helps in reducing friction, built-up edge formation, thermal distortion of the tool and the work. It reduces flank wear of the cutting tool and improves tool life; and

- iv Surface finish is improved significantly by high-pressure coolant in turning alloy steels. Surface finish is improved mainly due to reduction of wear and damage at the tool tip by the application of high-pressure coolant.

## ACKNOWLEDGEMENTS

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