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Chip Formation in Turning Medium Carbon Steel by Uncoated Carbide Inserts under Dry, Wet and High-Pressure Coolant Conditions

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ABSTRACT

The growing demand for high productivity machining and grinding particularly high strength and heat resistance materials need use of high cutting velocity and feed. Such machining and grinding inherently generate very large amount of heat and high cutting temperature, which not only reduces tool life but also impairs the product quality. Chip morphology (chip shape, colors and chip reduction coefficient) is a considerable instrument to predict optimum cutting parameters. It is very helpful in determining favorable machining environments. High production machining at high cutting velocity and feed rate generates large heat and high cutting temperature, which shortens the tool life and deteriorates the job quality. This problem becomes more severe during difficult to machine materials and under dynamic loading conditions. The conventional cutting fluids are not that effective in such high production machining particularly in continuous cutting of materials like steels. Machining of soft, sticky and ductile materials yields long continuous chips and rapid tool wear due to inefficient action of the cutting fluids. High-pressure coolant machining is starting to establish itself as a method for substantial increase of economical production in the metal cutting industry. Cutting with an excess amount of cutting fluids is still very common, even if a trend towards dry cutting is starting to grow fast. Research made in the past has shown the high potential with high-pressure coolant assisted machining compared to conventional cooling. The present work deals with experimental investigation in the role of high-pressure coolant jet on chip formation like chip shape, color and chip reduction coefficient in plain turning of medium carbon steel rod at different cutting velocities and feed rates by two types of carbide inserts (SNMM and SNMG) of different geometry. Chip morphology is used to differentiate, compare and choose the best among these three environments-dry, wet and high-pressure coolant systems. Compared to the other machining (dry and wet), high pressure coolant machining performed much superior mainly due to substantial reduction in cutting zone temperature enabling favorable chip formation and chip-tool interaction.

Keywords: HPC, Turning, Chip shape, Chip color and Chip reduction coefficient

1. INTRODUCTION

Chip morphology refers to the characteristics of the chips produced in a manufacturing process, which aids in analyzing the performance of the machine tool, process parameters and product quality. If one masters in chip reading, it is easy to control throughput, turning costs, tool life and surface finish, leading to better process economics and increased process security.

These issues are particularly timely today, because many companies are operating multiple shifts to meet growing market demand and running unattended turning operations. By interpreting chip size, shape, color, and direction, one will know how effectively the tools and machines are performing. It is possible to have peace of mind regarding unattended operation, because chip disposal is controlled, smooth and reliable. Whether unattended or attended, chip formation can wreak havoc on machine uptime.

If unattended turning operations are run, concerns about chip control, throughput, surface finish, edge security and tool wear can be minimized to an extant. It is recommended that when first cuts are run, one should not limit oneself to checking workpiece, but also read your chips. The chip characteristics will tell immediately what machining data or tooling need fixing, so that we can adjust them. In addition, if anyone can become a chip expert who reads the chips properly, will be among a minority that understands that there is more to a chip than just a piece of metal.

Chip formation processes in metal cutting, particularly in turning and drilling, have been studied extensively [1–10]. Elbestawi et al. [11], Ng et al., [12], and Becze et al. [13] have investigated chip formation and tool wear in high speed end milling of hardened steels. Ning et al. [14] have classified the chips observed from ball end milling of H13 hardened steel into four types: complete, unstable, critical, and severe chips. Kobayahsi [15] have discussed the mechanics and chip morphology in turning and drilling of plastics. The unique mechanical properties of elastomers, particularly the large elongation to fracture and low thermal conductivity, can greatly affect the chip formation during machining.

In general, chip formation in machining can be categorized as forming continuous, discontinuous, or serrated chips [9, 10]. The serrated chip with accompanying adiabatic shear band is commonly observed in machining materials that exhibit poor thermal properties with either low thermal conductivity or low specific heat. For materials with such poor thermal properties, the heat generated in the shear zone does not have time to escape. This raises the temperature in the shear zone and leads to thermal softening and adiabatic shear band formation.

In machining ductile metals even with cutting fluid, the increase in cutting velocity reduces the ductility of the work material and causes production of long continuous chips, which raises the cutting temperature further [16].

The chip-formation mechanism analysis is an effective tool for deeper understanding of cutting process. During different cutting processes, different mechanisms of chip-formation appear. The analyses cover the chip segmentation frequency, chip shape and dimensions, and the size of deformed and un-deformed parts of chip segments. The results show that there exists a close relationship among these chip parameters. It is clear that to maintain optimum cutting condition and get the best performance, it is essential to know how to interpret the chips and to generate optimum chips in different materials and operations.

2. EXPERIMENTAL CONDITIONS

Machining of steel involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip tool contact. The temperature generate during high speed machining falls a great negative impact on machining quality, tool life, surface roughness, tool wear etc. The temperature becomes more intensive when cutting velocity and feed are increased for high speed machining and work materials are relatively difficult to machine for their high strength, hardenability, and lessen thermal conductivity. It has already been observed through the literature review that high pressure coolant jet provides the solution of those high speed machining problems.

A number of cutting velocity and feed have been taken over relatively wider ranges keeping in view the industrial recommendations for the tool-work materials undertaken and evaluation of role of variation in V_c and S_o on effectiveness of high-pressure coolant. Keeping in view less significant role of depth of cut (t) on cutting temperature, saving of work material and avoidance of dominating effect of nose radius on cutting temperature, the depth of cut was kept fixed to only 1.0mm, which would adequately serve the present purpose.

For the quantitative analysis in the experiment for different uncoated cutting tools of SNMM and SNMG were used in four different feed rates. From the experiment the chips were collected and scrutinized the shapes and colors and calculated the chip reduction coefficient. Then for various conditions curves for different velocities versus different chip reduction coefficients are drawn to compare the result.

The setup the High Pressure Coolant is shown in the Fig.1. The setup consists of motors, vena pump, flow control valve, regulatory valve, relief valve, oil tank, oil indicator, pressure gauge, nozzle etc. The conditions of the present experiments are given in Table-1.

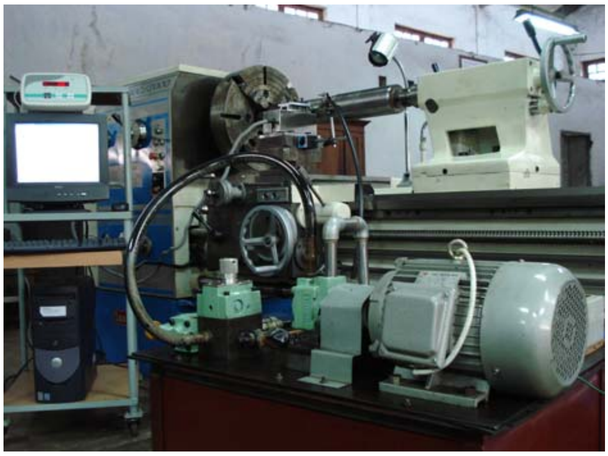


Fig 1: Photographic view of the experimental set-up

Table 1: Experimental conditions

Machine tool	: Lathe Machine (China) 10hp
Work material	: Medium carbon steel (φ200 X 600 mm)
Cutting tool	
Cutting insert	: SNMM and SNMG, Sandvick
Tool holder	: PSBNR 2525M12
Working geometry	: -6°,-6°,6°, 15°, 75°, 0.8 (mm)
Process parameters	
Cutting velocity	: 69, 99, 120, 156 and 195m/min
Feed rate	: 0.10, 0.13, 0.16 and 0.20 mm/rev
Depth of cut	: 1.0 mm
High-pressure coolant (HPC)	: 40 bar, coolant: VG-68 cutting oil, 6 l/min
Environments	: Dry, wet and HPC

The form, colour and thickness of the chips also directly and indirectly indicate the nature of chip-tool interaction influenced by the machining environment. The chip samples were collected during both short run and long run machining for all the tool and V_c-S_o combinations under dry, wet and high-pressure coolant conditions. The form and colour of all those chips were noted down. The thicknesses of the chips were repeatedly measured by a slide calliper to determine the value of chip reduction coefficient, ζ (ratio of chip thickness after and before cut) which is an important index of machinability. The chip samples collected while turning the steel by both the inserts of configuration SNMG and SNMM at different V_c-S_o combinations under dry, wet and high-pressure coolant conditions have been visually examined and categorized with respect to their shape and colour.

The results of such categorization of the chips produced at different conditions and environments by the medium carbon steel at different V_c-S_o combinations have been shown in Table-2and Table-3 respectively. The actual forms of the chips produced by the medium carbon steel during machining by the SNMM and SNMG type inserts at different V_c-S_o combinations under dry, wet and high-pressure coolant conditions are shown in Fig.2 and Fig.3.

Another important machinability index is chip reduction coefficient, (ratio of chip thickness after and before cut). For given tool geometry and cutting conditions, the value of depends upon the nature of chip-tool interaction, chip contact length and chip form all of which are expected to be influenced by cryogenic cooling in addition to the levels of V_c and S_o. The variation in value of chip reduction coefficient (ξ) with change in tool configuration, V_c and S_o as well as machining environment evaluated for medium carbon steel have been plotted and shown in Fig.4 and Fig.5.

3. EXPERIMENTAL RESULT AND DISCUSSIONS

The pattern of chips in machining ductile metals are found to depend upon the tool geometry particularly rake angle, levels of V_c and S_o, nature of chip-tool interaction and cutting environment. In absence of chip breaker, length and uniformity of chips increase with the increase in ductility and softness of the work material, tool rake angle and cutting velocity unless the chip-tool interaction is adverse causing intensive friction and built-up edge formation.

Table-1 shows that the medium carbon steel, when machined by the pattern type SNMM insert under both dry and wet condition produced long and snarled unbroken chips at all V_c and S_o combinations. The geometry of the SNMG insert is such that the chips of this steel first came out continuously, got curled along normal plane and then hitting at the principal flank of this insert broke into pieces with regular size and shape. When machined under high-pressure coolant condition, the SNMM and SNMG inserts produced helical broken chips and their back surface appeared much brighter and smoother. This indicates that the amount of reduction of temperature and presence of high-pressure cooling enabled favourable chip-tool interaction and elimination of even trace of built-up edge formation. Fig.2 and Fig.3 typically shows that even at high feed of 0.20 mm/rev the same tool-work combination provided relatively longer and smoother chips when machined with dry and wet environments.

The colour of the chips have also become much lighter i.e. metallic from blue depending upon V_c and S_o due to reduction in cutting temperature by cryogenic cooling. It is important to note in Tables-2 as well as in Fig.2 that the role of high-pressure coolant has been more effective in respect of form and colour of the chips when the same steel was machined by the groove type SNMM inserts. Such improvement can be attributed to effectively larger positive rake of the tool and better cooling by the jets coming along the groove parallel to the cutting edges. The favourable effects of high-pressure on chip formation were found to be relatively less in case of the other steels possibly because their stronger chips adhering intimately on the rake surface did not allow high-pressure coolant to reach and that effectively cool the chip-tool interface when those steels were machined by the SNMG inserts as can be seen in the tables from Table-2 as well the figures from Fig.3. However, it is also evident from the aforesaid tables and figures that when this steel was machined by the SNMG insert, high-pressure coolant could provide relatively more favourable effects on chips' form for the reasons already mentioned.

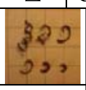
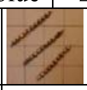
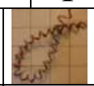
Almost all the parameters involved in machining have direct and indirect influence on the thickness of the chips during deformation. The degree of chip thickening which is assessed by chip reduction coefficient, ζ, plays sizeable role on cutting forces and hence on cutting energy requirements and cutting temperature. The value of ζ usually decreases with the increase in V_c particularly at its lower range due to plasticization and shrinkage of the shear zone for reduction in friction and built-up edge formation at the chip-tool interface due to increase in temperature and sliding velocity. In machining steels by tools like carbide, usually the possibility of built-up edge formation and size and strength of the built-up edge, if formed gradually increase with the increase in temperature due to increase in V_c and also S_o and then decrease with the further increase in V_c due to too much softening of the chip material and its removal by high sliding speed. It is also noted in Fig.4 and Fig5 that ζ decreased all along also with the increase in S_o expectedly due to increase in average rake angle with increase in uncut chip thickness. Fig.4 and Fig.5 show that high-pressure coolant has reduced the value of ζ particularly at lower values of V_c and S_o when machined by both the inserts. By high-pressure coolant applications, ζ is reasonably expected to decrease for reduction in friction at the chip-tool interface and reduction in deterioration of effective rake angle by built-up edge formation and wear at the cutting edges mainly due to reduction in cutting temperature.

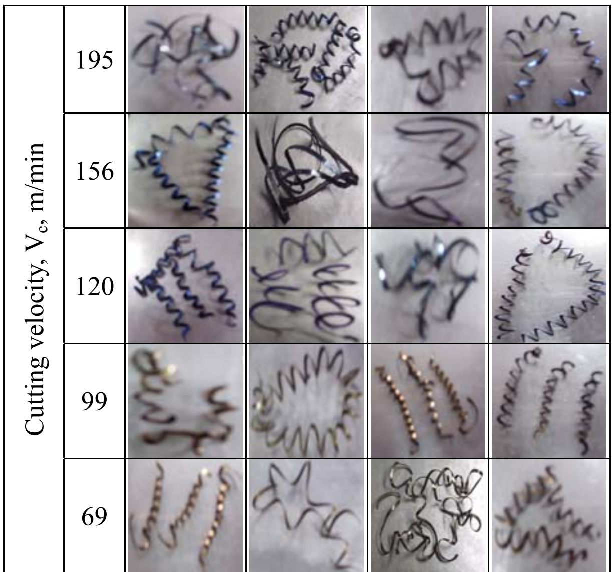
Table 2: Shape and color of chips produced during machining steel by SNMM (P-40) insert

V_c, m/min	S_o, mm/rev	Environment					
		Dry		Wet		HPC	
		shape	color	shape	color	shape	color
69	0.10	■	blue	♣	metallic	♣	metallic
99		■	blue	▲	metallic	♣	metallic
120		■	blue	▲	golden	♣	metallic
156		■	blue	▲	metallic	♣	golden
195		Δ	blue	▲	golden	▲	golden
69	0.13	Δ	blue	▲	metallic	♣	metallic
99		▲	blue	▲	metallic	□	metallic
120		Δ	blue	▲	golden	▲	golden
156		Δ	blue	▲	golden	■	golden
195		▲	blue	▲	golden	▲	golden
69	0.16	Δ	blue	▲	metallic	♣	metallic
99		□	blue	♣	golden	■	metallic
120		Δ	blue	▲	golden	▲	golden
156		Δ	blue	▲	golden	▲	golden
195		Δ	blue	▲	golden	▲	golden
69	0.20	□	blue	▲	golden	♣	metallic
99		■	blue	▲	metallic	♣	metallic
120		▲	blue	▲	metallic	♣	golden

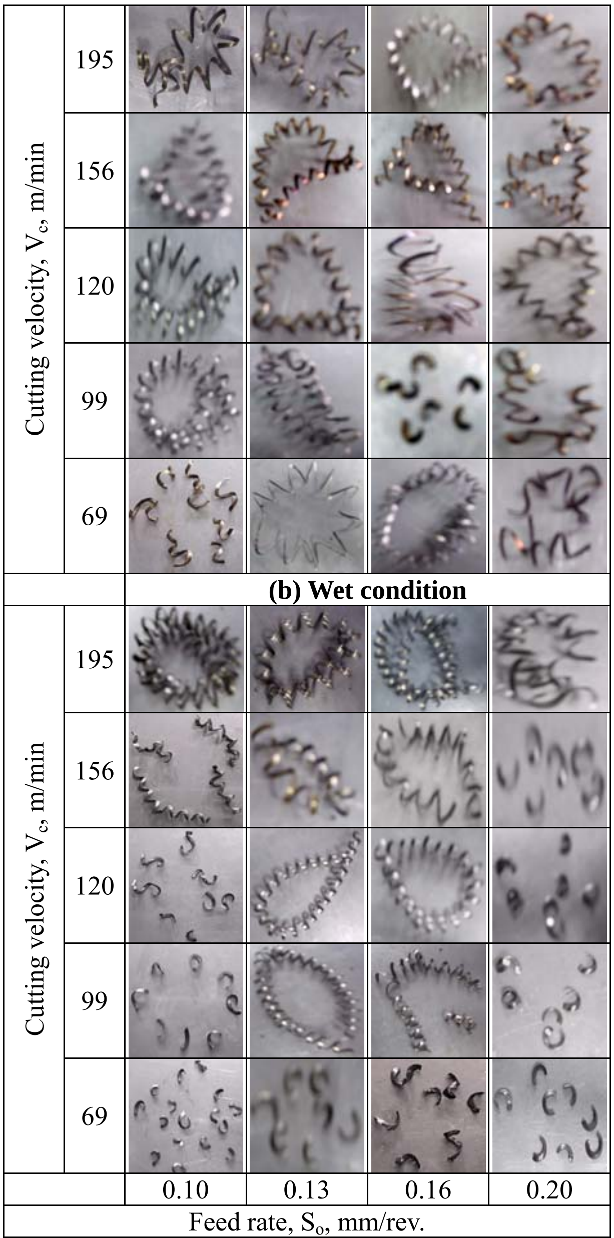
156		▲	blue	▲	golden	♣	golden
195		Δ	blue	▲	golden	Δ	golden

Table 3: Shape and color of chips produced during machining steel by SNMG (P-40) insert

V_c, m/min	S_o, mm/rev	Environment					
		Dry		Wet		HPC	
		shape	color	shape	color	shape	color
69	0.10	■	blue	♣	golden	Δ	metallic
99		♣	blue	▲	golden	Δ	metallic
120		Δ	blue	Δ	golden	Δ	metallic
156		Δ	blue	Δ	golden	Δ	metallic
195		▲	blue	Δ	blue	Δ	metallic
69	0.13	□	blue	♣	golden	♣	metallic
99		□	blue	Δ	golden	Δ	metallic
120		□	blue	Δ	golden	Δ	metallic
156		Δ	blue	Δ	golden	♣	metallic
195		Δ	blue	Δ	blue	Δ	metallic
69	0.16	♣	blue	□	metallic	♣	metallic
99		♣	blue	♣	golden	♣	metallic
120		♣	blue	♣	golden	Δ	metallic
156		Δ	blue	♣	golden	♣	metallic
195		Δ	blue	Δ	blue	Δ	metallic
69	0.20	♣	blue	♣	golden	♣	metallic
99		♣	blue	♣	golden	♣	metallic
120		♣	blue	♣	golden	♣	metallic
156		■	blue	♣	golden	♣	metallic
195		Δ	blue	Δ	blue	♣	metallic
chip shape							
group		c & ε-type broken chips (♣)	medium helical broken chips (■)	long helical broken chips (□)	long helical unbroken chips (▲)	long and snarled unbroken chips (Δ)	



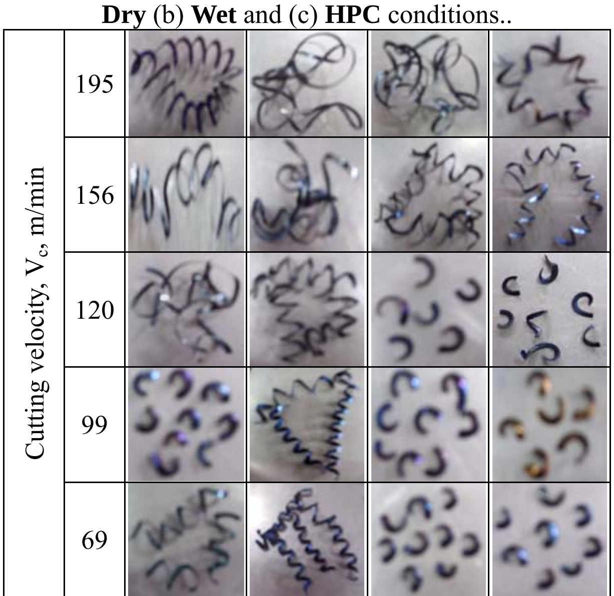
(a) Dry condition



(b) Wet condition

(c) HPC condition

Fig 2: Chips produced by **SNMM** (P-40) insert under (a) **Dry** (b) **Wet** and (c) **HPC** conditions..



(a) Dry condition

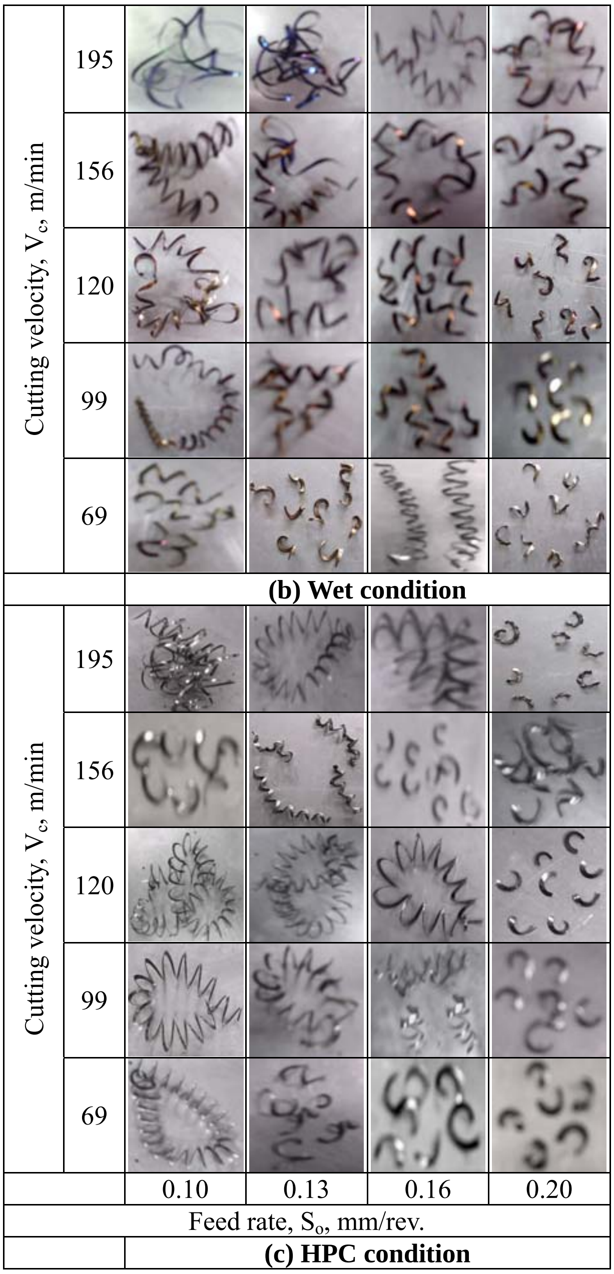


Fig 3: Chips produced by **SNMG** (P-40) insert under (a) **Dry** (b) **Wet** and (c) **HPC** conditions.

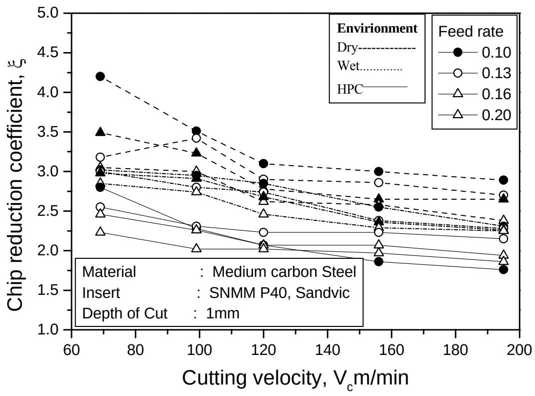


Fig 4: Variation in chip reduction coefficient with that of V_c and S_o in turning medium carbon steel by **SNMM** insert under dry and HPC conditions

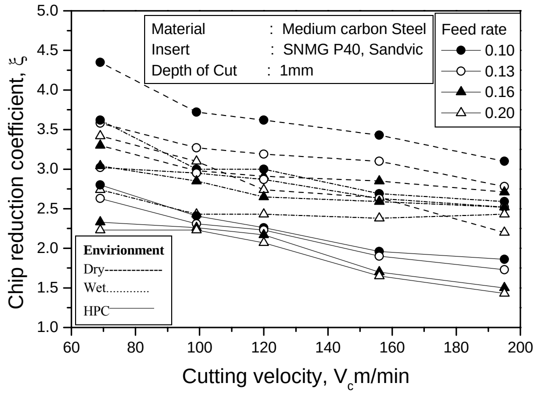


Fig 5: Variation in chip reduction coefficient with that of V_c and S_o in turning medium carbon steel by **SNMG** insert under dry and HPC conditions

4. CONCLUSION

From the aforesaid experimental investigations the following conclusions can be drawn.

(1) High pressure cooling jet changes the mode of chip formation and improves chip tool interaction during the machining. The cause behind it may be the high pressure coolant to some extent lift up the chip reducing the curl radius acting as a wedge in between the chip and the cutting tool. The high pressure cooling jet efficiently enters into the chip tool interface.

(2) High pressure cooling jet reduces chip reduction coefficient that is also favorable for chip formation in compare to that of dry and wet conditions.

(3) For recent industrial development and continuous progress it is essential to determine a way to increase speed and feed rate to increase productivity more. But increasing speed and feed rates lead to problems such as tool wear, tool life reduction, surface quality reduction, etc. As a result, it is necessary to develop a new system which fulfils this requirement with fewer criticisms. From recent technologies, High Pressure Cooling Jet has shown a performance up to the desirable standard.

(4) In this experiment, we analyzed chip morphology to determine the suitability of High Pressure Cooling Jet with uncoated carbide inserts. It is recommended that more experiments should take place to see the effect of High Pressure Cooling Jet on Tool wear, Tool life and surface roughness with coated carbide inserts.

5. ACKNOWLEDGMENTS

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