Wear Behavior of Coated Carbide under High-pressure Coolant Jet Assisted Machining of Stainless Steel

A Project Thesis

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Abstract

In machining, tool wear is a natural phenomenon and it eventually leads to tool failure. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality particularly when the work piece is quite strong, hard and heat resistant. Conventional cooling methods are not only ineffective but also deteriorate the working environment by producing harmful gasses and smokes. Machining of Austenitic Stainless Steel and other difficult-to-cut materials requires instant heat transfer from the cutting edge of the tool to improve tool life. Supply of high-pressure coolant assistant jet provides the best answer. This project deals with experimental investigation on the role of high pressure cooling by capillary action of insoluble oil on tool wear and product quality in turning of Austenitic Stainless Steel at different speed-feed combinations by two types of Coated Carbide inserts of different geometry. The main objective of the proposed work is to make on the major turning characteristics tool wear and surface roughness of coated carbide tool under high pressure coolant jet assisted machining of stainless steel. The methodology of the present work is to design and development of a high pressure coolant and a suitable nozzle for cooling jet. At the same time analysis of data by measuring tool wears under optical microscope, assessing tool wear under SEM and measuring surface roughness. The encouraging results include significant reduction in tool wear rate, dimensional inaccuracy and surface roughness by high pressure cooling application mainly through reduction in the cutting zone temperature and favorable change in the chip–tool and work–tool interaction.

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Chapter-1

Introduction

1.1 Introduction

Metal cutting is one of the most important processes carried out in industries. The purpose of any metal cutting operation commonly called machining is to produce a desired, shape, size and finish of a component by removing the excess metal in the form of chips from a rough block of material. Consequently the primary objective in metal cutting is the production of chips, although these chips are only a means to an end and are discarded. The exact mechanism of metal cutting briefly stated is that a cutting tool exerts a compressive force on the work piece. Under this compressive force the metal of the work piece is stressed beyond the yield point causing the material to deform plastically and shear off. The plastic flow takes place in the localized region called shear plane, which extend from the cutting oblique up to uncut surface ahead of the tool. The sheared material begins to flow along the cutting tool face in the form of small pieces called chips. The compressive force applied to form the chips is called cutting force. The flowing chips cause wear of cutting tool. Heat is produced during shearing action. The heat generated raises the temperature of the work, cutting tool and the chips. The temperature rise in the chip-tool interface tends to soften it and causes loss of keenness in the cutting edge leading to its failure. The cutting force, heat and abrasive wear are thus the basic features of the metal cutting process.

It is believed that heat is carried away from the tool and the work by means of cutting fluid which at the same time reduce the friction between the tool and the chip and work and also facilitates the chip formation. The conventionally applied cutting fluid can do this job properly at normal cutting conditions where the feed and depth of cut are very low. But in case of ductile metal and under high speed-feed condition conventionally applied coolant is completely ineffective to do so as the bulk and progressive contact between tool face and the flowing chips cannot allow the coolant to enter into the interface where maximum temperature attains. Moreover, water soluble-coolant is a major source of environmental pollution, soil contamination and carrier of bacteria borne diseases like lung cancer, dermatitis and others.

Cutting temperature effects also can be effectively controlled by the use of extremely heat and wear resistant cutting tools like cubic boron nitride (CBN), PCBN, diamond, poly crystalline diamond (PCD) etc. But manufacturing of those tools involves high cost and special techniques as well as time consuming. Due to high cost of those tools its use is limited only in special type of parts manufacturing processes like aerospace, power plants etc. Also very low temperature coolant (LN2 and liquid carbon dioxide) can change the performance of metal machining. But at nitrogen rich atmosphere notch wear increases and at high temperature carbon dioxide decomposes to its constituents that initiate oxidation while metal cutting. And due to high cost of cryogen it is also limited to general purpose use. Though injection of conventional coolant in a form of mist (MQL) improves machinability index to some extent, it cannot remove the aforesaid problems associated with conventional coolant.

Besides, tool wear governs the geometrical, surface and subsurface qualities of the work piece. These work piece characteristics influence important finished job properties, such as residual stresses. The thermal effects resulting from tool wear accelerate the shape deviation of the part, which is why compensation strategies become necessary. That's why; the importance of tool wear monitoring is also implicit in the possible economic advantages. If worn tools could be changed in good time, it would be possible to avoid the production of waste. Furthermore, tool costs could be reduced noticeably by an optimized exploitation of the tool life. An accurate estimation of tool wear would even make it possible to adjust the tool position in order to meet geometric specifications and to guarantee a certain surface quality of the work piece.

With the advent of carbide tools and other new methods of machining, the efficiency of the metal cutting operations has improved to a certain extent under normal cutting conditions. However, improving the performance of metal cutting operations in high speed machining and in the case of machining difficult-to-machine materials is still a major concern. It was found that the efficiency of metal cutting operations depends to a large extent on the effectiveness of the cooling/lubrication provided. It was found that a high pressure coolant/lubricant jet injected below the flowing chips onto the tool-chip interface provides effective cooling/lubrication and consequently improves the machining performance of the tool.

A number of attempts were made in the past to improve cooling/lubrication in high speed machining and in the case of machining of difficult-to-machine materials by the use of a high pressurized coolant/lubricant jet to overcome these problems. In general, all attempts to apply pressurized cutting fluid can be classified into three groups, namely, coolant/lubricant jet injected into tool-chip interface through an external nozzle, jet delivered into the clearance between flank and machined surface, and jet injected directly through the tool rake face into tool-chip interface. The results achieved by these investigators were very encouraging. Cutting forces were reduced, chip shape, surface quality and tool life improved, thereby increasing the metal removal rate, and improving the overall performance of the machining operation.

From all these investigations, it was evident that applying cutting fluid in the form of a jet at higher pressures into the cutting zone is more beneficial than conventional cooling techniques. Until now, investigations carried out in this direction were, in general, limited to low pressures where the cutting fluid is not capable of penetrating deep enough into the tool-chip interface to dissipate heat as quickly as possible from the appropriate regions in the cutting zone.

This is why high-pressure jet of insoluble oil at high-speed combination was tried to check the effectiveness of such system on tool wear of carbide insert.

Chapter-2

Literature Review

2.1 Introduction

In machining, the advantages of high cooling technology include significant improvement to tool life, effective chip segmentation and efficient cooling and lubrication. The penetration of the high-energy jet into the tool–chip interface reduces the temperature gradient and eliminates the seizure effect, offering adequate lubrication at the tool–chip interface with a significant reduction in friction in addition to alteration of the chip flow conditions resulting in the lowering of component forces and consequently tool wear rate. The success of implementing this technology across the metal removal industries will therefore depend on increased research activities providing credible data for in depth understanding of high-pressure coolant supplies at the tool–chip, tool–work piece interfaces and integrity of machined components.

2.2 Literature Review

Machining is inherently characterized by generation of heat and high cutting temperature. At snch elevated temperature the cutting tool if not enough hard, may lose their form stability quickly or wear out rapidly resulting in increased cutting forces, dimensional inaccuracy of the product and shorter tool life. The magnitude of the cutting temperature increases, though in different stages, with the increase of the cutting velocity, feed and depth of cut, as a result, high production machining is constrained by rise in temperature. This problem increases further with the increase in strength and hardness of the work material [1, 2].

While removal of material in the form of chips new surfaces are cleaved from the work piece accompanied by a large consumption of energy. The mechanical energy necessary for the turning operation is transformed into heat leading to conditions of high temperature and severe thermal / frictional conditions at the tool- chip interface [3].

It was observed that, in machining ductile metals producing long chips, the chip tool contact length has a direct influence on the cutting temperature and thermo-chemical wear of the cutting tools [4]. The cutting temperature becomes maximum on the rake face of the cutting tool at a certain distance from the cutting edge where cratering occurs. Such high rake face temperature can also raise the temperature at the flank of the tool.

It suggested that in machining ductile metals, the heat and temperature developed due to plastic and rubbing of the chips with the tool may cause continuous build up of welded debris, which affects machining operation [5]. Stainless steels are generally considered difficult-to-machine because of high work-hardening rate, toughness and ductility. Therefore, tools will be subjected to high frictional heat, and chips will have a tendency to stick and cause severe built up edge formation.

The heat generated during machining also raises the temperature of the cutting tool tips and the work-surface near the cutting zone [6]. Due to such high temperature and pressure the cutting edge deforms plastically and wears rapidly, which lead to dimensional accuracy, increase cutting forces and premature tool failure. On the other hand, the cutting temperature, if it is high and is not controlled, worsen the surface topography and impairs the surface integrity by oxidation and introducing residual stresses, micro-cracks and structural changes.

Some researcher reported that the hardness, plastic modulus and the fracture toughness of the tool decline with increase in cutting temperature, which accelerates tool wear rate [7]. Moreover, thermal stresses in tool increase with the temperature resulting in more cracks in the tool and premature failure of the tool. The high cutting temperature also causes mechanical and chemical damage of the finished surface.

Some observed that the contact length between the tool and chip has a direct influence on the cutting temperatures and the amount of heat energy that is dissipated in the tool which enhances thermally activated chemical wear [8]. Maximum temperature is found to develop on the rake face of the tool also raises the temperature at the flanks of the tool. Chip shape formation is a very common way to evaluate machinablity of some material, especially in manufacturing condition at floor. But chip shape as well as white layer features might be also used for defining transition region from conventional to high speed machining [9].

In addition to usual flank wear and crater wear the cutting tools often attain notching on the flanks and grooving on the rake surface at the outer edge of the engaged portion of the cutting edges. On the major cutting edge the grooving wear occurs at the extreme end of the depth cut and is characterized by smaller multiple notches. Several mechanisms have been proposed to explain grooving wear. Such as 1) development of a work hardened / abrasive oxide layer on the cut surface 2) formation of thermal cracks due to sleep temperature gradient 3) presence of side-spread material at the edge of the newly cut surface and 4) fatigue of tool material due to cutting force fluctuations at the free surface caused by lateral motions of the edge of the chip [10].

It also reported that in machining ductile metals, the chip contact length plays significant role on the chip and tool temperature which becomes almost at the centre of the chip-tool contact surface where then crater wear begins and groove intensively [11].

The high specific energy required in machining under high cutting velocity and unfavorable condition of the machining results in very high temperature which reduces the dimensions accuracy and tool life by plastic deformation and rapid wear of the cutting points [12-14]. On the other hand such high temperature, if not controlled, impairs the surface integrity of the machined component by severe plastic flow of the work material, oxidation and by inducing large tensile residual stresses, micro cracks and subsurface cracks. This problem is further intensified while machining for faster material removal in bulk and finishing very hard, strong and difficult to machine materials, which are gradually advancing with the vast and rapid developments in the modern areas, like aerospace technology and nuclear science.

Past research has been focused on the temperature and its distribution in the cutting zone because it is believed that it has a direct impact on tool life [15]. The primary function of cutting fluids is to rednce this cutting temperature and increase tool life [16]. The cutting fluids are believed to reduce cutting temperature either by removing heat as a coolant or reducing heat generation as a lubricant. In addition, the cutting fluid has a practical function as a chip-handling medium [17]. Cutting fluids also help in machining of ductile materials by reducing or preventing formation of build up edge (BUE), which degrades the surface finish [18].

Besides, tool wear development with cutting time shows, after high initial wear rate, flank wear land width (V_B) increase in a linear behavior. It is observed that tool nose radii in the range of 0.8-2.4 mm seams to have no effect on tool wear process, showing comparable wear rate and similar tool life [19].

It has been experienced that there was more tool wear when cutting with coolant than cutting dry in case of machining AISI 1020 and AISI 4340 steels by M-2 high speed steel cutting tool [16] . It also reported that at the first stage of machining (first 40 second or so), tool wear was faster in wet cutting than in dry cutting. Later on, the wear rate stabilized and was somewhat the same for both dry and wet cutting [20].

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, as schematically shown in Fig 2.1 due to continuous interaction and rubbing with the chips and the work surfaces respectively [21-23]. Among the aforesaid wears, the principal flank wear is the most important because it raises the cutting forces and the related problems.

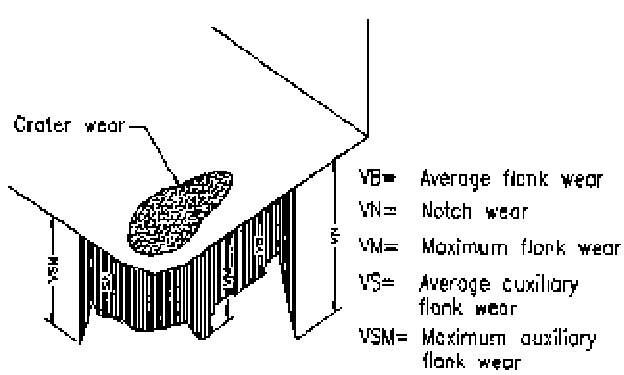


Fig. 2.1 Geometry of wear of turning tool

The magnitude of the cutting temperature increases though in different degree with the increase of cutting velocity, feed and depth of cut. At such elevated temperature the cutting tools if not enough hot hard may lose their form stability quickly or wear out rapidly resulting in increased cutting force, dimensional inaccuracy of the product and shorter tool life [24]. This problem increases further with the increase in strength and hardness of the work material.

During machining, the cutting tool generally undergoes both flank wear and crater wear [11]. Flank wear generally causes an increase in cutting forces, dimensional inaccuracy and vibration. Crater wear takes place on the rake face of the tool where the chip slides over the tool surface.

Surface roughness is formed as a result of the repetition of the cutting tool tip moving along the work piece at the desired feed rate during machining processes. This relative motion interacts in a complex manner, depending on work piece properties, tool vibration and metal shearing during the chip formation. Since structures of the machine tooi are non-rigid and the work piece surface is no homogenous, random resistance against cutting causes a stick-slip process between the chip and tool and chip breaking etc. Cutting parameters (i.e. speed, depth of cut and feed rate, chip loads and chip formations, dynamic characteristics of the tool-spindle structure and non homogenous hardness distribution in the work piece) are generally considered to be major factors affecting this random relative vibration between the tool and work piece. The average surface roughness can be assumed to be the result of the supervision of theatrical profile computed from cutting kinematics and of the oscillatory profile determine by the relative vibration between the cutting edge and the work piece [25].

Surface finish influences not only the dimensional accuracy of the machined parts, but also their properties whereas surface finish describes the geometric features of the surfaces. Surface integrity pertains to properties, such as fatigue life and corrosion resistance, which are influenced strongly by the type of surface produced. Factors influencing surface integrity are (a) temperature generated during processing (b) metallurgical (phase) transformations and (c) surface plastic deformation, tearing and cracking [26].

With respect to theoretical models to predict the surface roughness in the high speed machining, these are really limited, being empirical the majority of them and based in experiments in laboratory conditions. In the present there are only a few mathematical relations between surface parameters and cutting conditions allowing us to predict surface roughness in a correct and general form [27].

Wearing of the cutting tools not only causes loss of the cutting edges or tip of the inserts but loss of the entire insert after wear of all the corners. From an environmental perspective, therefore, the significant waste is not the portion of the tool worn away by the tool-work contact, but the remaining portion of the tool that is disposed after its useful life [28].

A major portion of the energy is consumed in the formation and removal of chips. 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 [29].

The application of cutting fluid during machining operation reduces cutting zone temperature and increases tool life and acts as lubricant as well [17]. Also It states that without cooling and lubrication, the chip sticks to the tool and breaks it in a very short cutting time [30]. It reduces cutting zone temperature either by removing heats as coolant or reducing the heat generation as lubricant. In addition it serves a practical function as chip- handling medium. But it has been experienced that lubrication is effective at low speeds when it is accomplished by diffusion through the work piece and by forming solid boundary layers from the extreme pressure additives, but at high speeds no sufficient lubrication effect is evident [31]. The ineffectiveness of lubrication of the cutting fluid at high speed machining is attributed to the inability of the cutting fluid to reach the actual cutting zone and particularly at the chip-tool interface due to bulk or plastic contact at high cutting speed. On the other hand, the cooling and lubricating effects of cutting fluid influence each other and diminish with increase in cutting velocity [24]. Since the cutting fluid does not enter the chip-tool interface during high speed machining, the fluid action is limited to bulk heat removal only.

Minimum quantity lubrication is the same in fashion and small amount of heat is reduced like dry cooling. Usually the high cutting temperature is controlled by profuse cooling [32]. Sometimes, the costs of tools may increase with the use of minimum lubrication, due to the increase of tool wear [33]. The MQL system has shown encouraging potentials for precision machining at low feed and high-speed conditions [34]. Considering the use of the MQL in machining, the vapor, the mist and the smoke of oil can be considered undesirable sub-products, characterizing an increase in pollution by suspension in the air [35]. In Germany, the maximum pollution concentration in the air under the mist form is limited in to 5 mg/m^3 and for vapor oil the limit is 20 mg/m^3 [35]. During machining with MQL only the top most layer of the work piece experiences bulk cooling and air-coolant mixture can't reach to the tool tip due to the hindrance caused by the spiral flute of the drill bit and the counter flow of the chip.

However, such profuse cooling with conventional cutting fluid is not able to solve these problems fully even when employed in the form of jet or mist. With the advent of some modern machining process and harder materials and for demand for precision machining, the control of machining temperature by more effective and efficient cooling has become extremely essential [36-38]. In addition, conventional Cutting fluids, most of the times, are difficult and expensive to recycle, can cause skin and lung diseases to the machine operator and air pollution [33].

Flood cooling in the cutting zone can effectively reduce the cutting temperature when machining at lower speed conditions with significant sliding region and where relatively low cutting temperatures are generated. The coolant also acts as a lubricant, thus minimizing friction and lowering component forces and consequently tool life. There is very limited access of the coolant to the tool-workpiece or tool-chip interfaces, which are mainly under seizure condition when machining at high speed conditions. Coolants tend to be vaporized by the high temperature generated close to the tool edge, forming a high temperature blanket that renders their cooling effect ineffective [39]. The film boiling temperatures of conventional cutting fluids is about 350°C [40].

The main problem with conventional coolant is that it does not reach the real cutting area [41]. The extensive heat generated evaporates the coolant before it can reach the cutting area. The high cutting forces generated during machining will induce intensive pressure at the cutting edge between the tool tip and the workpiece. 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. With the use of high-pressure coolant during machining, the tool life and surface finish are found to improve significantly [42-44] which is said to be due to the decrease in heat and cutting forces generated. There have been several studies on applying coolant at high pressure at the tool–chip interface, focused on a stationary single cutting edge in a turning operation.

Cryogenic cooling is an efficient way of maintaining the temperature at the cutting interface well below the softening temperature of the cutting tool material. This technology is exploited mainly in the grinding industry because of the high specific energy requirements, which results in high grinding zone temperature which if not properly controlled will lead to surface damage [39]. It was found that in cryogenic machining high cutting and thrust forces are generated than in conventional and flood cooling or dry machining applications. This anomaly is attributed to the fact that sub zero temperatures has the consequence of increasing hardness and strength of the work material, hence higher forces are generated with cryogenic cooling [25]. Tool wear rates when machining titanium alloy Ti-6Al-4V with cemented carbide using Liquid nitrogen and under conventional cooling at a cutting speed of 132 m min^{-1}, feed rate of 0.2 mm rev^{-1} and a depth of cut of 1.0 mm showed a five fold increase in flank wear for tools subjected to the conventional cooling [45]. This type of cooling is effective but not cost effective. Cryogen handling is difficult and it may cause cold diseases if operator wears no safety wear.

High–pressure jet of conventional coolant has been reported to provide some reduction in cutting temperature [46]. High-pressure coolant can often cut cycle times in half or better and improve surface finish and double or quadruple tool life while delivering a reduction in cycle time [47]. The idea of delivering coolant under high pressure to the cutting region in order to increase tool life during machining began in early 1950s [48]. The primary objective of this machining technique is to significantly reduce the temperature generated at the tool-workpiece and tool-chip interfaces when cutting at higher speed conditions. This is achieved by directing coolant under high pressure at the chip-tool interface. This process can also achieve high chip breakability and control through increased chip up curl and compressive stress [39]. It stated that ability to deliver coolant at high pressure very close to the critical point on the secondary shear zone could improve machinability at higher speed conditions. The credibility of this technique of coolant delivery has been thoroughly investigated over the years. The high speed coolant jet traverses the surface faster, thus significantly lowering the film boiling action of the coolant at the cutting area. This consequently minimizes heat transfer to the cutting tool. The high pressure coolant jet creates a hydraulic wedge between the tool and the workpiece, penetrating the interface with a speed exceeding that required even for high speed machining and also alters the chip flow conditions [1]. The penetration of the high energy jet into the tool-chip interface reduces the temperature gradient and eliminates the seizure effect, offering an adequate lubrication at the tool-chip interface with a significant reduction in friction [39].

The temperatures generated by the cutting speeds of today's advanced tooling can actually prevent low-pressure flood coolant from entering the cutting zone. The majority of the cooling and lubricating aspects of a flood coolant stream are lost as the coolant is vaporized prior to entering the cutting zone [47]. It is the great problem for machining, HPC play well role to minimize this type of problem. Better solution can be found from it that HPC systems generate high velocity coolant streams moving at several hundred mph. This high-speed coolant easily penetrates the vapor barrier to effectively lubricate and cool the tool. In fact, when machinists apply high-pressure coolant to a longstanding process, which has always produced dark blue chips, they are often amazed that the same or even higher speeds and feeds produce shiny, silver chips that are cool to the tonch. The high pressure of the coolant breaks up chips and forces them up the flutes and ont of the hole. Cycle times go down, because the pecking process is eliminated while spindle speeds and feed rates can be increased. With higher feed rates, chips tend to form better.

The essence of the problem (then and now) with standard low pressure coolant systems is that so much heat is produced that the coolant boils away before it can reach the chip- tool interface, where metal is actually cut [43]. The snper heated steam forms a barrier that low-pressure coolant can't penetrate. Effective cooling does not occur and there is little real lubrication provided. Unfortunately, the vapor barrier that forms is not powerful enough to keep chips from falling back into the chip-tool interface and causing damage. Properly applied high pressure and high volume coolant prevents this vapor barrier from forming by causing a localized pressure increase. So mnch liquid is forced into the cutting zone that heat is removed and no vapor can form because of the pressurization. Properly applied high-pressure, high-volume coolant prevents the formation of a vapor barrier by causing a localized pressure increase [49-51]. This force liquid into the cutting zone, removing heat, providing lubrication, and flushing chips away from the cut. Damage from heat and chips are eliminated, and tools can cut until they wear out. High-pressure coolant discourages chip welding, prevents the damaging chemical reactions that may occur at high temperatures, and allows drills to last longer [52].

High-pressure coolant also provides lubricity by blasting lubricating fluid between the chip and the cutting edge at hundreds of miles per hour [15]. Combined with much lower temperature, this increased lubricity often causes surface finishes to be twice as good. With conventional coolant, the cutting edge comes up to a very high temperature as it enters the cut, and stays hot until it finishes the cut and is exposed to an extreme thermal shock as the coolant quenches the exposed tool.

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. High-pressure is often the solution to getting the coolant to the target so it can cool, lubricate, and sometimes perform its third function-breaking chips that do not break neatly with ordinary machining processes [47]. High-pressure coolant reduces or eliminates the random tool failure from chip damage, resulting in much improved consistency of the machining process.

Cutting fluids have the dual tasks of cooling the cutting surface and flashing chip. In some operations such as drilling, for example, cutting fluid is important to remove the chips from inside the holes, thus preventing drill breakage [53-54]. They also help to control cutting-face temperature and this can prolong tool life, improve cut quality, and positively influence part finish. It has the benefit of a power full stream that can reach onto the cutting area. provides strong chip removal and in some cases enough pressure to deburr [46]. Possibility of controlling high cutting temperature in high production machining by some alternative method has been reported. High-pressure coolant injection technique not only provided reduction in cutting forces and temperature but also reduced the consumption of cutting fluid by 50% [46]. It was reported that a coolant applied at the cutting zone through a high-pressure jet 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 [44].

2.3 Summary of Review

The mechanical energy necessary for the machining operation is transformed into heat, leading to conditions of high pressure, high temperatures and severe thermal and frictional conditions, consequently making the metal cutting process more inefficient in terms of tool life, dimensional accuracy and material removal rate.

Also, product quality and overall economy in manufacturing by machining, particularly to meet the challenges thrown by liberalization and global cost competitiveness, insists high material removal rate and high stability and long life of the cutting tools. However, high production machining, grinding and drilling with high cutting velocity, feed rate and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature. Such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the surface integrity of the product and quality. Longer cut under high cutting temperature cause thermal expansion and distortion of the job particularly if it is slender and small in size, which lead to dimensional and form inaccuracy.

The surface quality of the products also deteriorates with the increase in cutting temperature due to built-up-edge formation, oxidation, rapid corrosion and induction of tensile residual stress and surface micro-cracks. These problems are more predominant in drilling where cutting temperature is, as such, very high due to much higher specific energy requirement and cutting velocity. Such problem becomes more acute and severe if the work materials are very hard, strong and heat resistive and when the machined or ground part is subjected to dynamic or shock loading during their functional operations. Therefore, it is essential to reduce the cutting temperature as far as possible.

However, improving the performance of metal cutting operations in high speed machining and in the case of machining difficult to machine materials is still a major concern. Efficiency of metal cutting operations depends largely on the effectiveness of the cooling/ lubrication provided. A flood of fluid directed over the back of the chip is the most common method of applying the cutting fluid. However, this method loses its effectiveness at higher cutting speeds. high pressure coolant/lubricant jet injected into the tool chip interface provides effective cooling/lubrication and consequently improves performance of the tool.

Chapter-3

Objectives

3.1 Objectives of the present work

Raising in temperature during metal machining cause several techno-economic problems on finished work piece, cutting tool and cutting area. High- pressure machining increases temperature. Some techniques have further been tested for effective reduction of cutting temperature. Among them Dry cutting with high resistant tool, flood cooling, minimum quality of lubricant and cryogenic cooling was used under low speed feed condition. One such technology that is gaining wide acceptance in the manufacturing industry is the use of high-pressure cooling technology. High-pressure cooling technique demonstrated a seven- to eight-fold increase in tool performance when machining steel. The cooling technology has now been perfected by the provision of efficient high-pressure cooling systems and tooling which is very appealing to industry in terms of costs.

The main objectives of the work is to study the effect of high pressure coolant jet on

i. Tool wear (average principal flank wear, notch wear, maximum flank wear, average flank wear and maximum auxiliary flank wear) and tool life
ii. Surface integrity along the surface finish and
iii. Product quality (dimensional deviation)

in turning stainless steel by coated carbide insert (SNMM & SNMG) under both dry and high pressure coolant conditions. These results are being expected to improve the tool life due to reduction in the cutting zone temperature enabling favorable chip formation and chip tool interaction. It will also provide reduction in tool wear, which will enhance the tool life, dimensional accuracy and surface finish.

Chapter-4

Experimental Investigation

4.1 Introduction

HPC machining has developed very quickly day by day. The idea of delivering coolant under high pressure to the cutting region in order to increase tool life during machining began in early 1950s [38]. Mainly, HPC has used in high production manufacturing industries where product quality and dimension accuracy are needed within acceptable limit and difficult-to-machine materials are processed to get the desired job. High speed machining is needed to increase prodnctivity in manufacturing technology. High speed machining is related with high temperature, such high temperature creates lot of problems. So, for reducing this high temperature HPC jet is used as a heat removing as well as lubricating agent.

4.2 Design And Fabrication Of The HPC Jet Delivery System

HPC set up contains motors, vena pump, flow control valve, regulating composite device and filter is shown in Fig 4.1 and Fig 4.2. These devices are mounted at the top of a tank that is made of mild steel sheets and angle bars. This tank contains the cnting oil that is used as a coolant. And the capacity of the coolant tank is 200 litters. A coolant indicator is mounted beside the wall of coolant tank; it is used to know the quantity of coolant present in the tank during machining. A 5 hp motor is used to operate the vena pump. A gear conpling is used between the vena pump and motor to transmit power. This pump pressurized the coolant to pass through the flow control. Flow control valve controls the amount of flow. The flow control valve is turned to minimize and maximize flow during machining. A relief valve has mounted with the flow control-regulating composite. Relief valve control the pressure and discharge excess oil to the tank. A pressure gauge is also mounted to observe the pressure of coolant. A direction control valve is used for changing the direction of supply. A perfect nozzle is used to snpply high-pressure coolant towards the cutting zone. From the nozzle, pressurized fluid impinged at the chip-tool interface and reduces the cutting temperature. A recycling pump and a filter are used to recycle the used coolant.

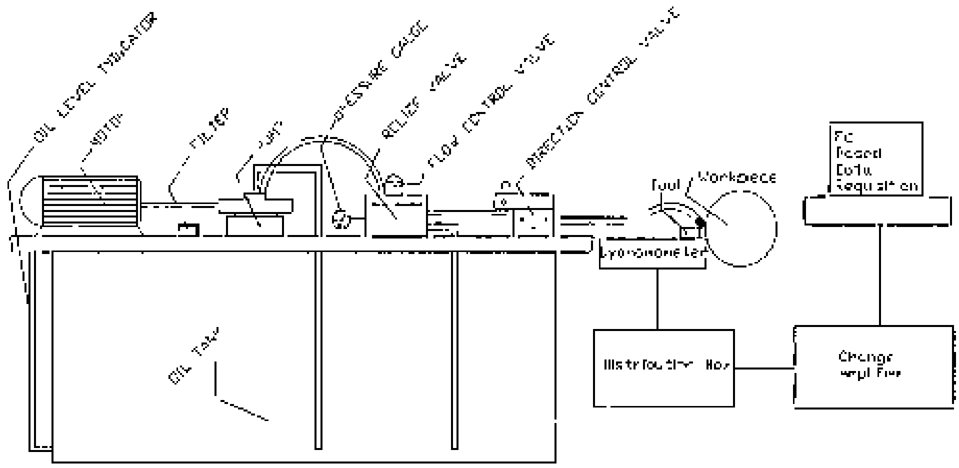


Fig. 4.1 Schematic diagram of High Pressure Coolant system

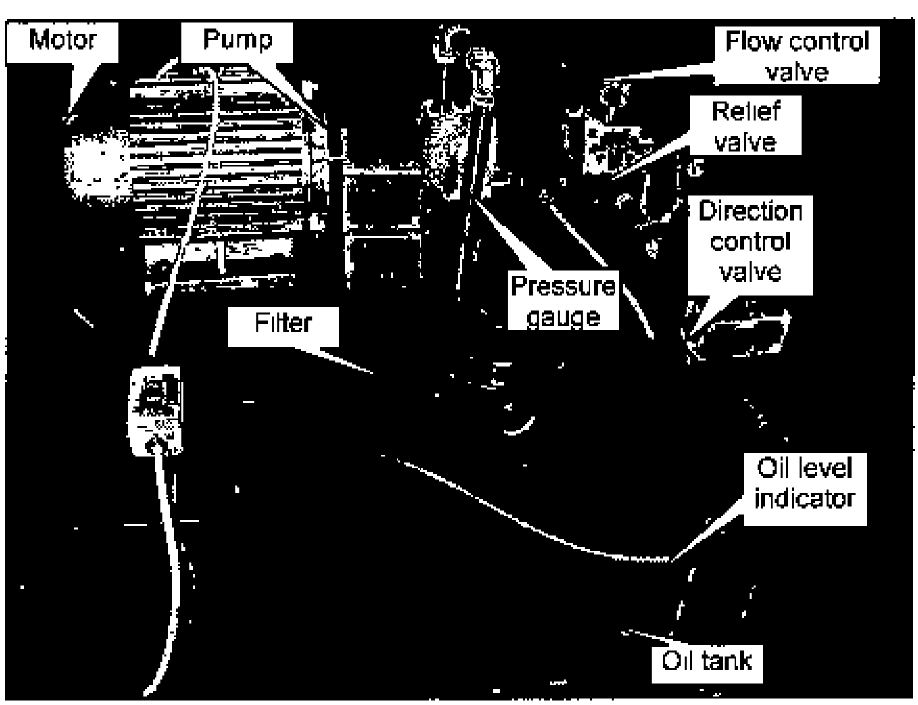
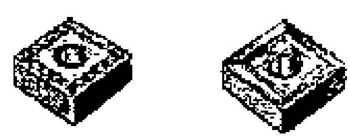


Fig. 4.2 Photographic view of high-pressure coolant delivery system

4.3 Experimental Procedure

The machining trials were carried out by turning a Stainless Steel (ø 140 mm × 600 mm) rod in a powerful and rigid lathe (10 hp) at different cutting velocities (Vc) and different feed (S_o) under both dry and high-pressure coolant condition. The high pressure coolant was supplied at an average flow rate of 6.0 l/min and pressure of 60 bars and directed via a nozzle on the tool holder to the region where the chip breaks contact with the tool. The photographic view of schematic diagram shown in fig 4.1 and the experimental setup is shown in fig.4.2. Coated carbide insert (TiCN + Al_2O_3) with ISO tool designations SNMG and SNMM was used for the machining trials. The conditions under which the machining tests have been carried out are briefly given in Table 4 .1.

Table 4.1 Experimental.conditions

Machine tool	:	Lathe Machine (France), 10 hp	
Work material	:	Stainless steel (φ114 X 600 mm)	
Cutting tool (insert)			
Cutting insert	:	Coated Carbide, SNMG and SNMM insert.	
		 SNMG 120408-26 SNMM 120408	
Tool holder	:	PSBNR 2525M12(ISO specification)	
Working tool geometry	:	Inclination angle	: -6°
	:	Rake angle	: -6°
	:	Clearance angle	: 6°
	:	Auxiliary cutting edge angle	: 15°
	:	Principal cutting edge angle	: 75°
	:	Nose radius	: 0. 8 mm
Process parameters			
Cutting velocity, V_c	:	93, 134, 188, 268 and 154	m/min
Feed rate, S_o	:	0.10, 0.14, 0.18.0.22	mm/rev
Depth of cut, t	:	1.0	mm
HPC supply	:	Pressure 60 bar, flow rate 6 litre/minute (through external nozzle).	
Environment	:	Dry, High pressure coolant system.	

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 HPC. The tool rejection criteria for roughing operation were considered. These values were considered in relation to ISO standard 3685 for tool life testing.

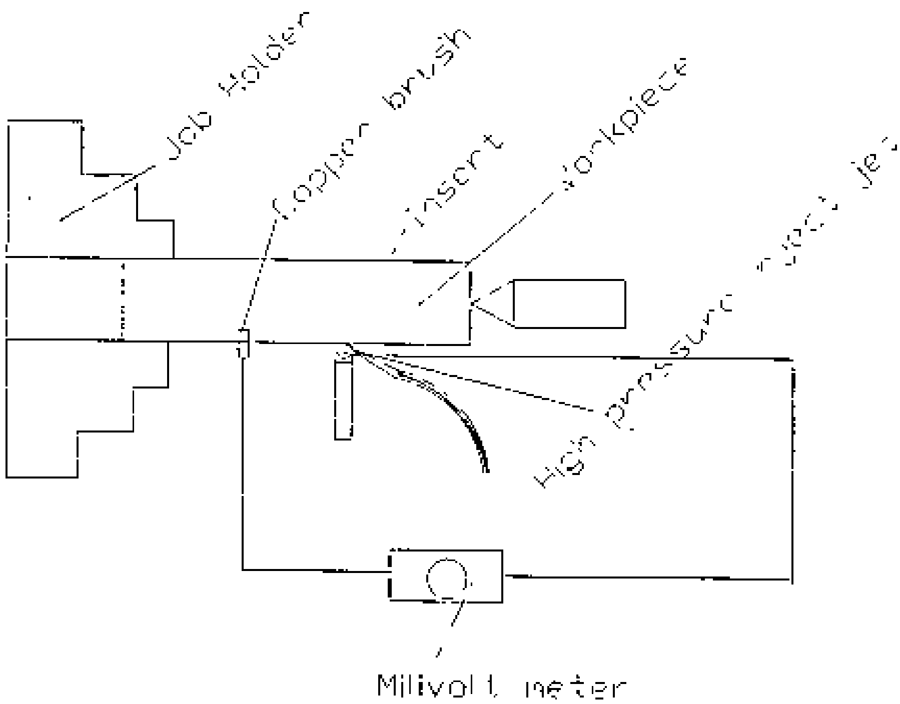


Fig. 4.3 Schematic of the tool-work thermocouple loop in turning stainless steel

A cutting tool was rejected and further machining stopped based on one or a combination of the following rejection criteria:

i. Average flank wear (mm) $\geq$ 0.4 mm
ii. Maximum flank wear (mm) $\geq$ 0.7 mm
iii Nose wear (mm) $\geq$ 0.5 mm
iv. Notching at the depth of the cut line (mm) $\geq$ 1.00 mm
v. Surface roughness (µm) $\geq$6.0 µm
vi. Excessive chipping (flaking) or catastrophic fracture of the cutting edge.

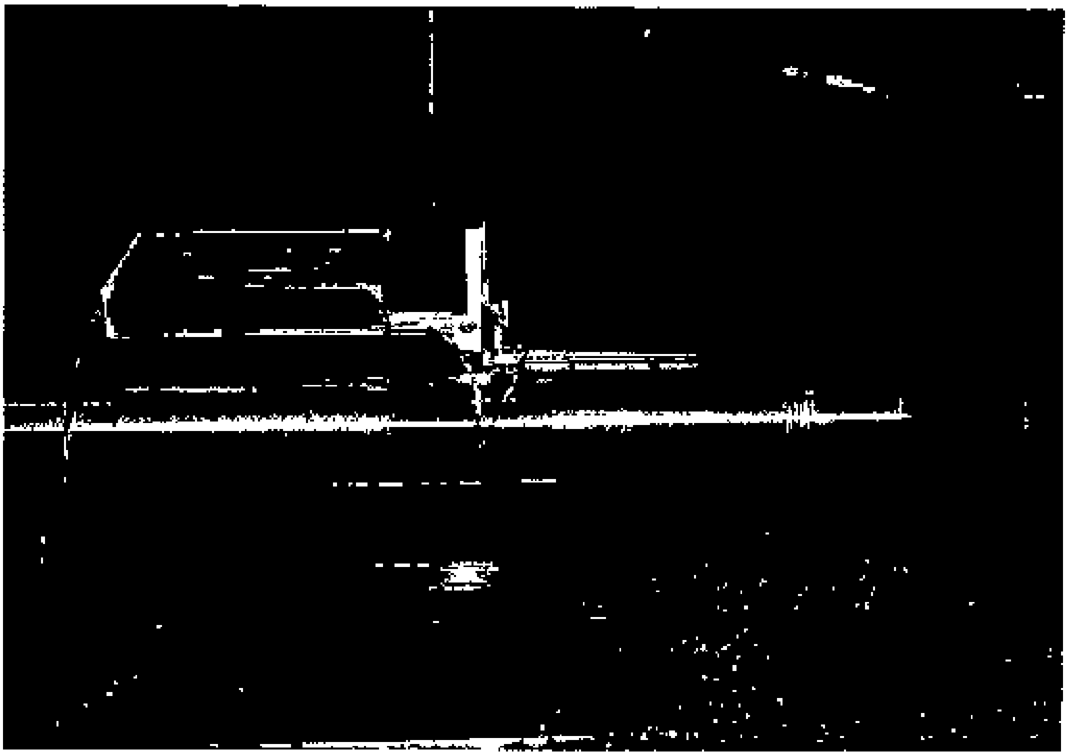


Fig. 4.4 Photographic view of the surface roughness measuring technique

The average cutting temperature was measured under all cutting conditions undertaken by simple but reliable tool-work thermocouple technique with proper calibration. The cutting tool wear at both the flanks were also measured at regular intervals under optical microscope (Carl Zeises, Germany) , While turning by the selected insert at a selected $V_c - S_o$- t condition under both dry and high pressure cooling conditions. The roughness of the machined surface after each cut was measured by a Talysurf (Sutronic 3+, Rank Tylor Hobson limited). The results are plotted and the major observations made are indicated in tabular form.

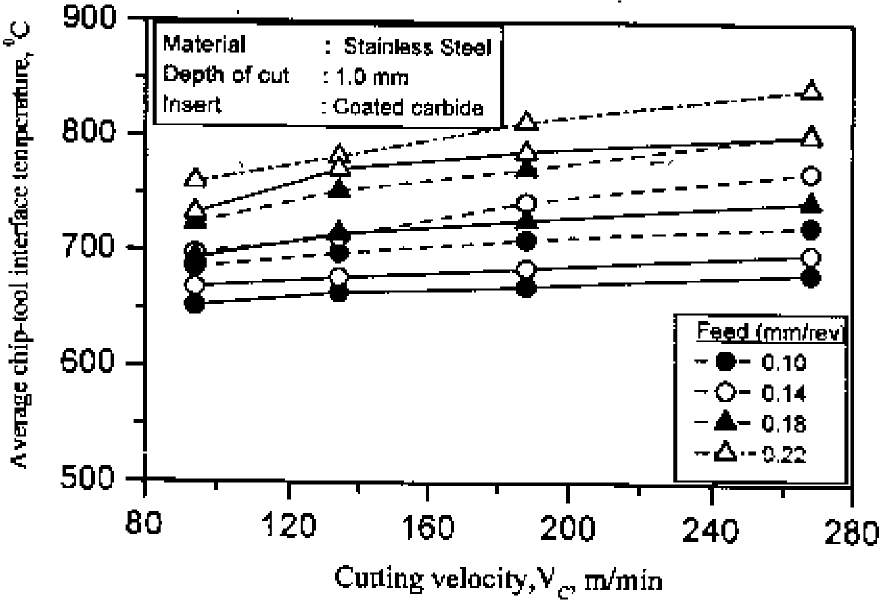
4.4 Experimental Investigation

4.4.1. Cutting Temperature

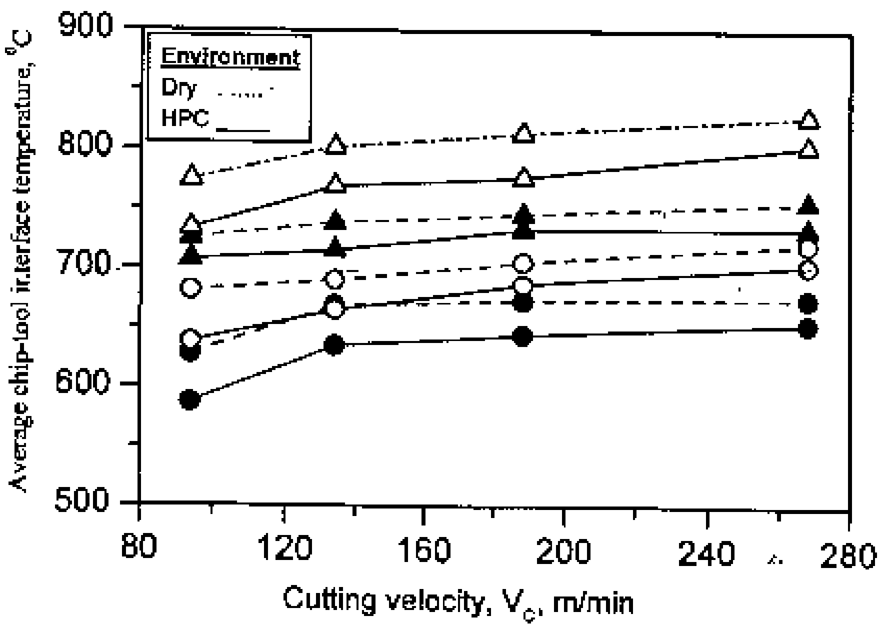
During machining any ductile materials, heat is generated at the (a) primary deformation zone due to shear and plastic deformation (b) chip-tool interface due to secondary deformation and sliding (c) work-tool interfaces due to rubbing. All such heat sources produce maximum temperature at the chip-tool interface, which substantially influence the chip formation mode, cutting forces and tool life. Therefore, attempts are made to reduce this detrimental cutting temperature. Conventional cutting fluid application may, to some extent, cool the tool and the job in bulk but cannot cool and lubricate expectedly effectively at the chip-tool interface where the temperature is high. This is mainly because the flowing chips make mainly bulk contact with the tool rake surface and may be followed by elastic contact just before leaving the contact with the tool. Bulk contact does not allow the cutting fluid to penetrate in the interface. Elastic contact allows slight penetration of the cutting fluid only over a small region by capillary action. The cutting fluid action becomes more and more ineffective at the interface with the increase in V_c when the chip-tool contact becomes almost fully plastic or bulk.

However, it was observed that the HPC jet in its present way of application enabled reduction of the average cutting temperature by about 5 to 10% depending upon the levels of the process parameters, velocity V_c and feed S_o and the types of the cutting Inserts. Even such apparently small reduction in the cutting temperature is expected to have some favourable influence on other machinability indices.

The cutting temperature generally increases with the increase in V_c and S_o, though in different degree, due to increased energy input and it could be expected that HPC would be more effective at higher values of V_c and S_o.



(a) SNMG insert



(b) SNMM insert

Fig. 4.5 Variation of chip-tool temperature with different cutting velocity at different feed rates under dry and HPC condition.

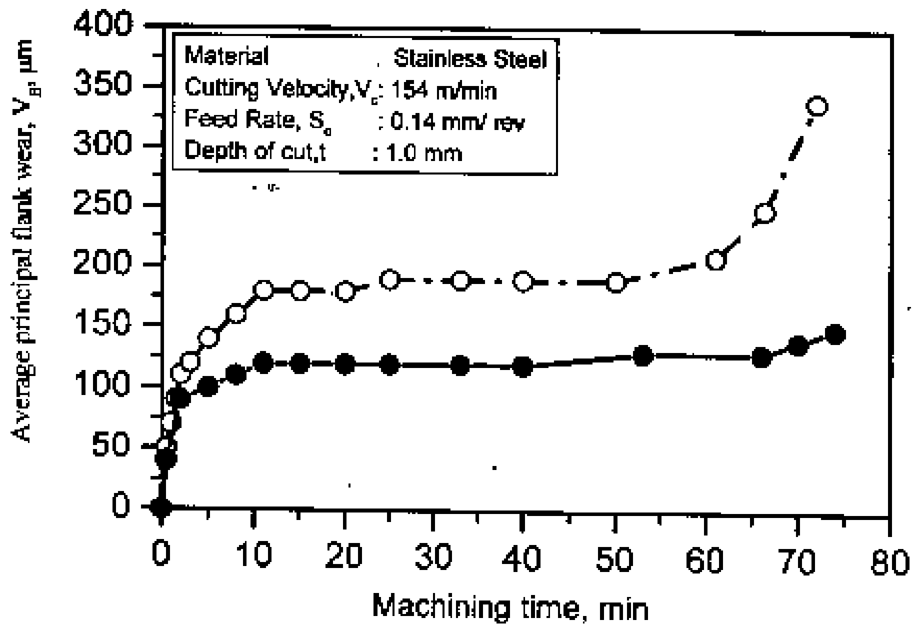
The cutting temperature generally increases with the increase in V_c and S_o, though in different degree, due to increased energy input and it could be expected that HPC would be more effective at higher values of V_c and S_o.

In the present work, the average chip-tool interface temperature could be effectively measured under dry and HPC condition very reliably throughout the experimental domain. However, the distribution of temperature within the tool, work and chip cannot be determined effectively using experimental techniques. The evaluated role of HPC on average chip-tool interface temperature in turning the steel by the coated carbide insert at different V_c and S_o under dry and HPC conditions have been shown in Fig.4.5 (a) and 4.5 (b).

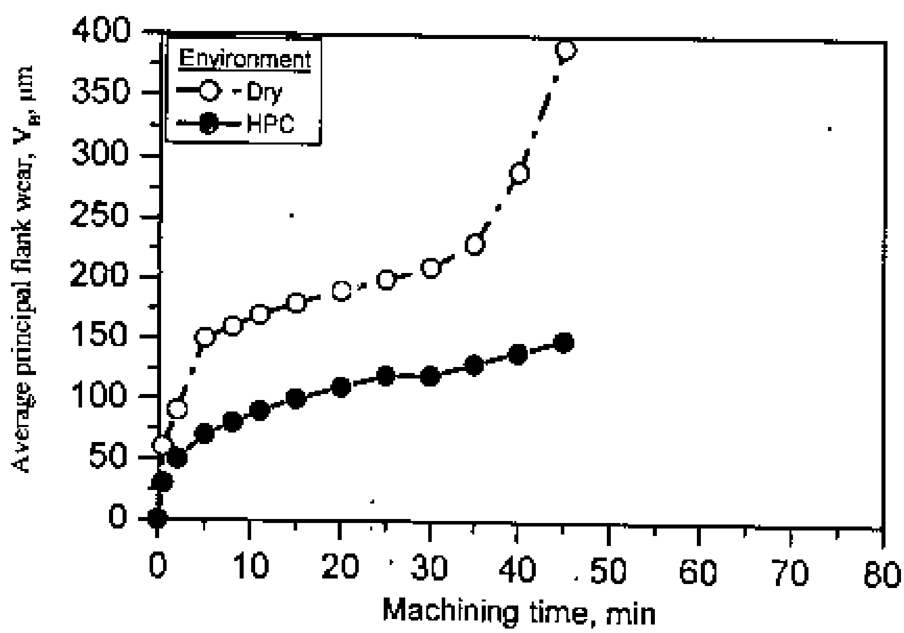
4.4.2 Tool Wear

The cutting tools in conventional machining, particularly in continuous chip formation processes like turning, generally fail by gradual wear by abrasion, adhesion, diffusion, chemical erosion, galvanic action etc. depending upon the tool-work materials and machining condition. Tool wear initially starts with a relatively faster rate due to what is called break-in wear caused by attrition and micro-chipping at the sharp cutting edges.

In machining, cutting tools may also often fail prematurely, randomly and catastrophically by mechanical breakage and plastic deformation under adverse machining conditions caused by intensive pressure and temperature and/or dynamic loading at the tool tips particularly if the tool material lacks strength, hot-hardness and fracture toughness. However, in the present investigations with the tool and work material and the machining conditions undertaken, the tool failure mode has been mostly gradual wear. Among the aforesaid wears, the principal flank wear (V_B) is the most important because it raises the cutting forces and the related problems. The life of carbide tool, which mostly fail by wearing, is assessed by the actual machining time after which

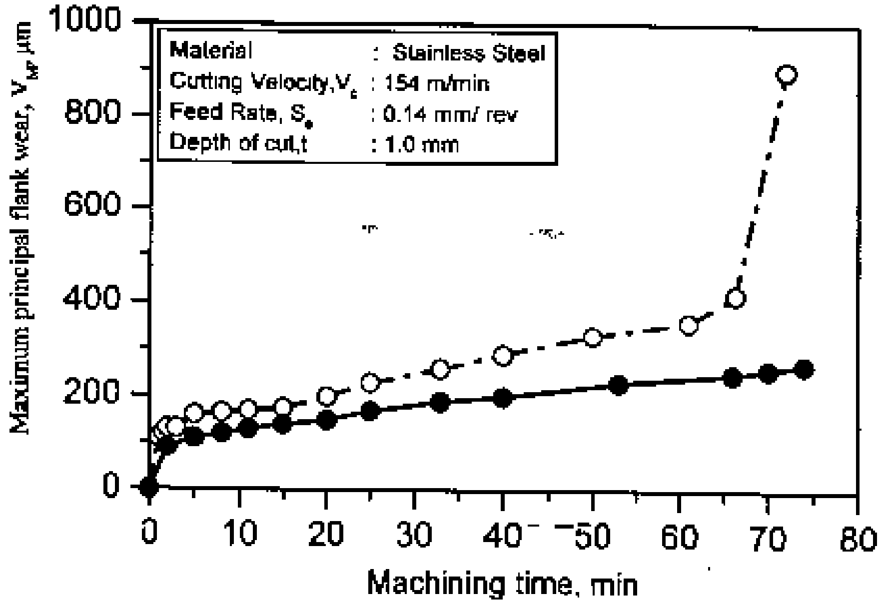


(a) SNMG insert

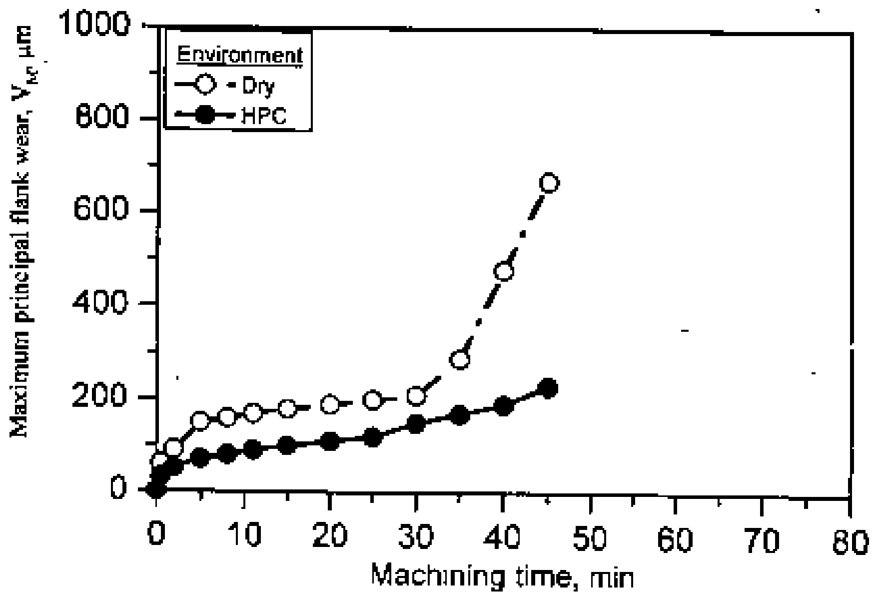


(b)SNMM insert

Fig. 4.6 Variation of average principal flank wear, V_B with machining time under dry and HPC conditions.



(a) SNMG insert



(b) SNMM insert

Fig. 4.7 Variation of maximum principal flank wear, V_M with machining time under dry and HPC conditions.

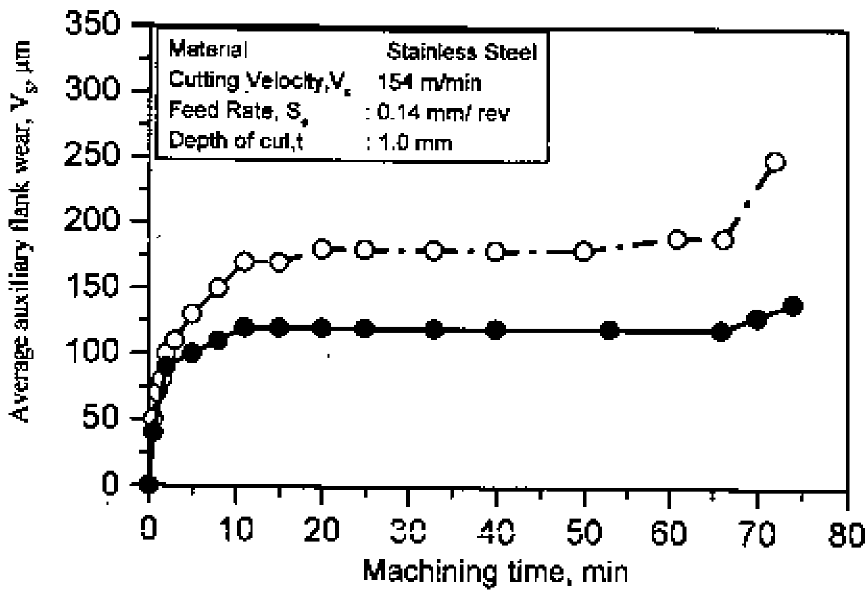
the average value (V_B) of its principal flank wear reaches a limiting value, like 0.3 mm. Therefore, attempts are to be made to reduce the rate of growth of flank wear (V_B) in all possible ways without sacrifice in MRR.

In our experiments, SNMG and SNMM type inserts are used at the same speed and depth of cut but moderately high cutting velocity under Dry, HPC cooling conditions have been shown in fig 4.6 (a) , 4.6 (b), 4.7 (a) and 4.7 (b) respectively.

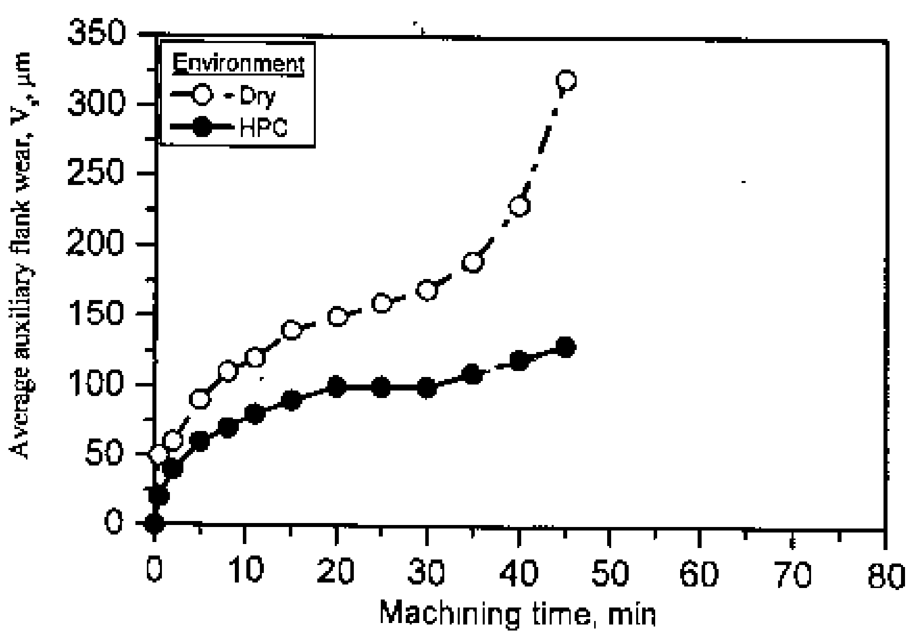
Another important tool wear criteria are average auxiliary flank wear, V_S, which governs the surface finish on the job as well as dimensional accuracy. Irregular and higher auxiliary flank wear leads to poor surface finish and dimensional inaccuracy.

At the same time, the growth of average auxiliary flank wear, V_S and maximum auxiliary flank wear V_{SM}, has been depicted in Fig.4.8 (a),4.8 (b), 4.9 (a) and 4.9 (b) for all the trials undertaken. The nature of growth of average auxiliary flank wear, V_S matches with that of V_B expectedly.

The pattern and extent of wear that developed at the different surfaces of the tool tips after being used for machining the Stainless steel over reasonably long period have been observed under SEM to see the actual effects of different environments on wear of the carbide insert of SNMG and SNMM configuration. The SEM views of principal and auxiliary flank wear of the worn out insert after about 74 minutes of machining of Stainless steel for SNMG inserts and 45 minutes of machining of Stainless steel for SNMM inserts under dry and HPC conditions have been shown in Fig.4.10, 4.11,4.12 & 4.13 respectively.

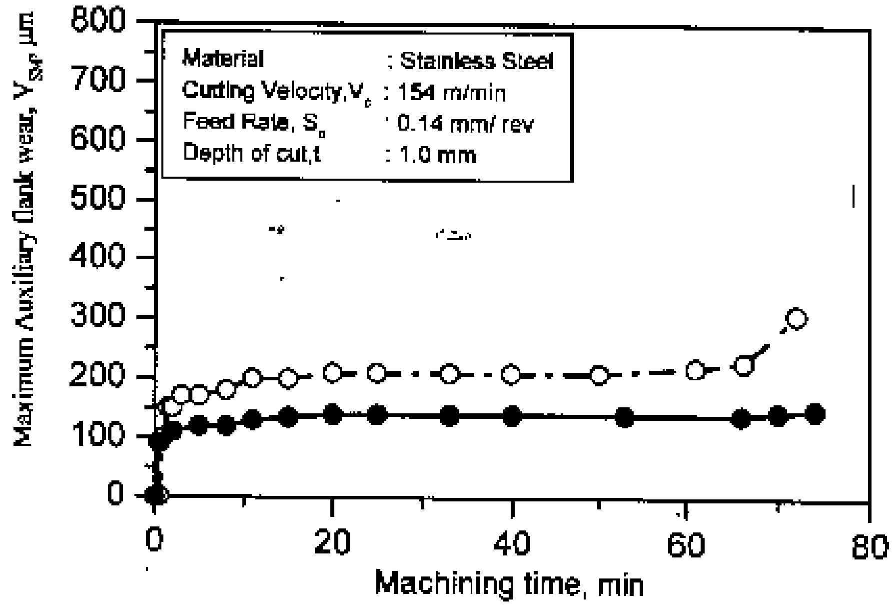


(a)SNMG insert

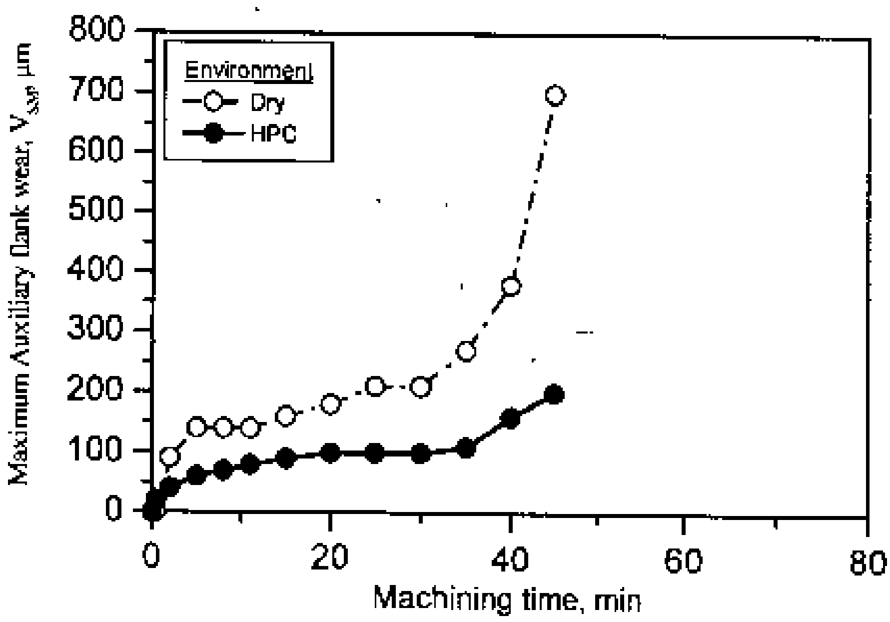


(b)SNMM insert

Fig. 4.8 Variation of average auxiliary flank wear, VS with machining time under dry and HPC conditions.

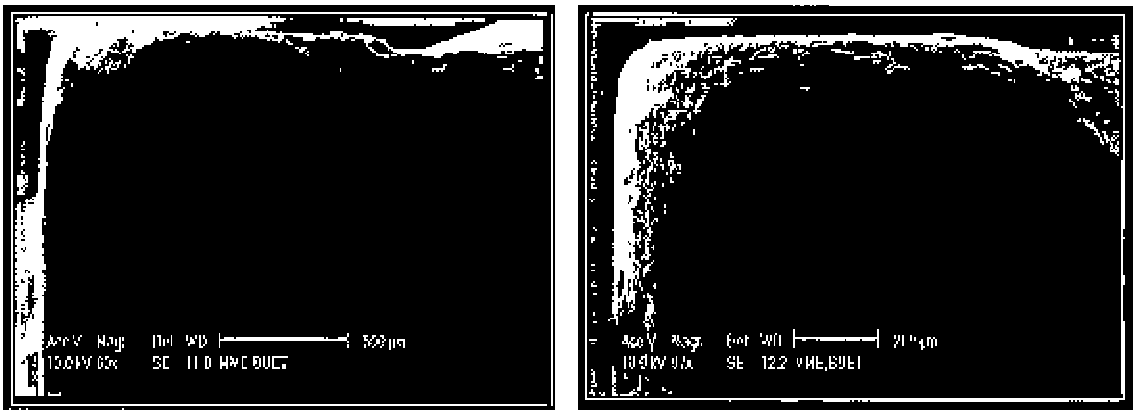


(a)SNMG insert



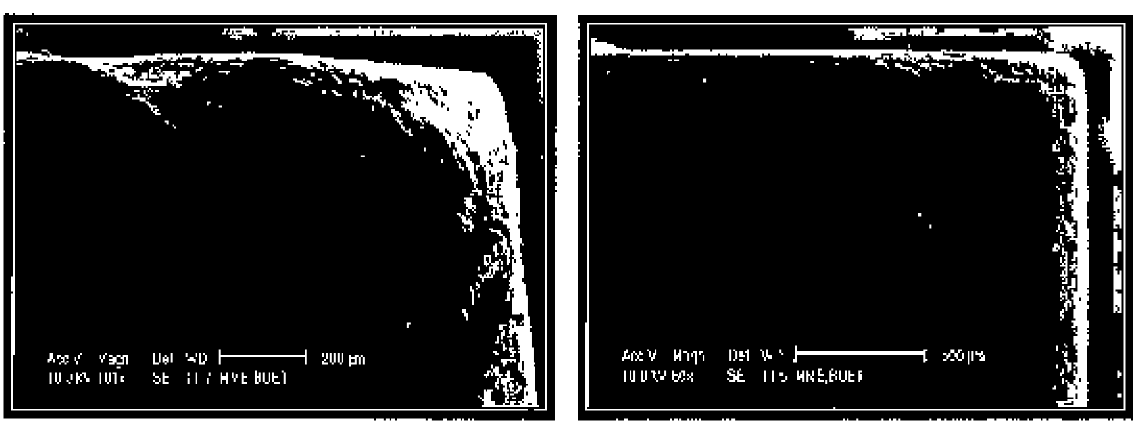
(b)SNMM insert

Fig. 4.9 Variation of maximum auxiliary flank wear, VSM with machining time under dry and HPC conditions.



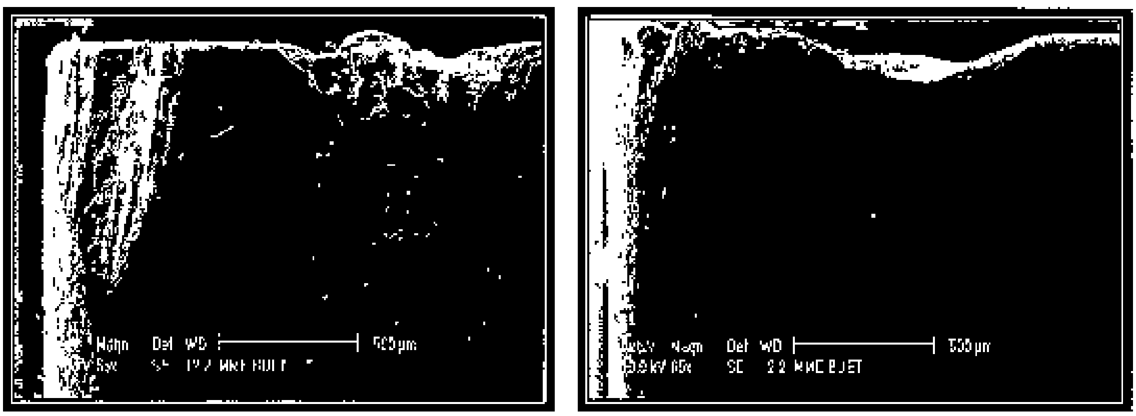
(a) Dry condition, 74 min (b) HPC condition, 74 min

Fig. 4.10 SEM views of principal flank wear of the worn out SNMG insert after machining under Dry, and HPC Conditions.



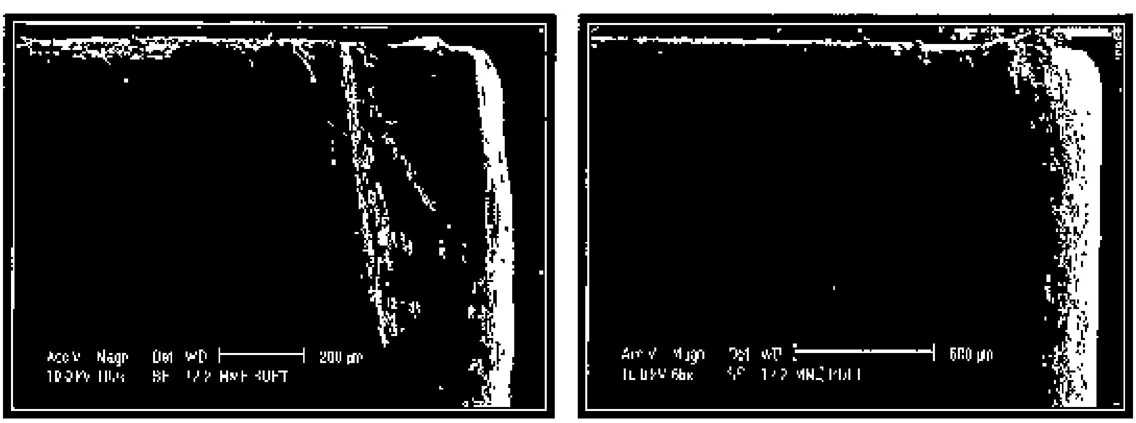
(a) Dry condition, 74 min (b) HPC condition, 74 min

Fig. 4.11 SEM views of Auxiliary flank wear of the worn out insert after machining under Dry and HPC conditions.



(a) Dry condition,45 min (b) HPC condition, 45 min

Fig. 4.12 SEM views of principal flank wear of the worn out SNMM insert after machining under Dry and HPC Conditions.



(a) Dry condition, 45 min (b) HPC condition, 45 min

Fig. 4.13 SEM views of Auxiliary flank wear of the worn out SNMM insert after machining under Dry and HPC conditions by insert.

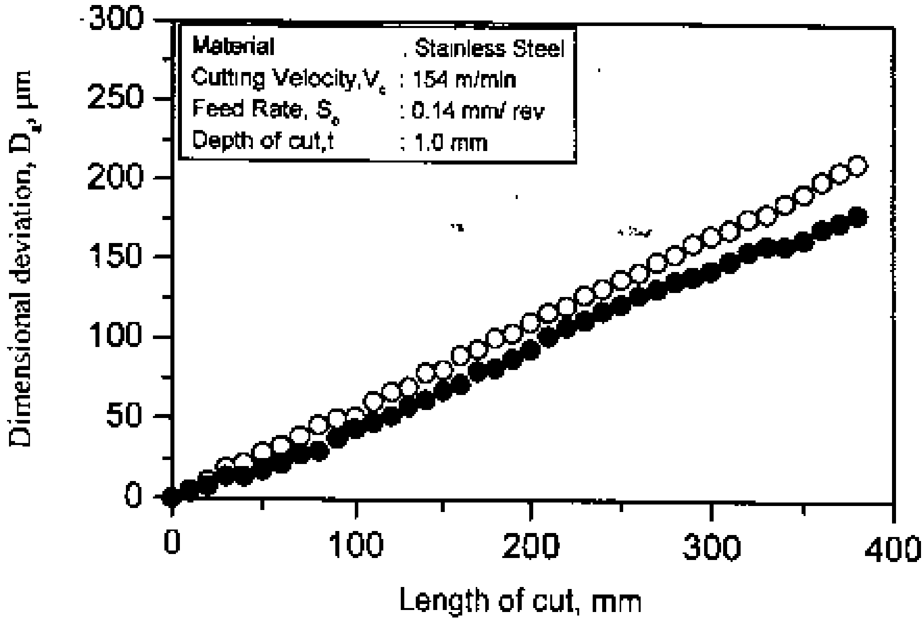
Under all the environments, abrasive scratch marks appeared in the flanks. There have also been some indications of adhesive wear in the insert. Severe groove wear at the flank surfaces were found in insert under dry and wet conditions. Some plastic deformation and micro chipping were found to occur under dry machining. Effective temperature control by HPC almost reduced the growth of groove wear on the main cutting edge as well as auxiliary cutting edges. Further, the figure clearly shows reduced average principal flank wear and average auxiliary flank wear under HPC condition.

4.4.3. Dimensional Deviation and Surface Roughness

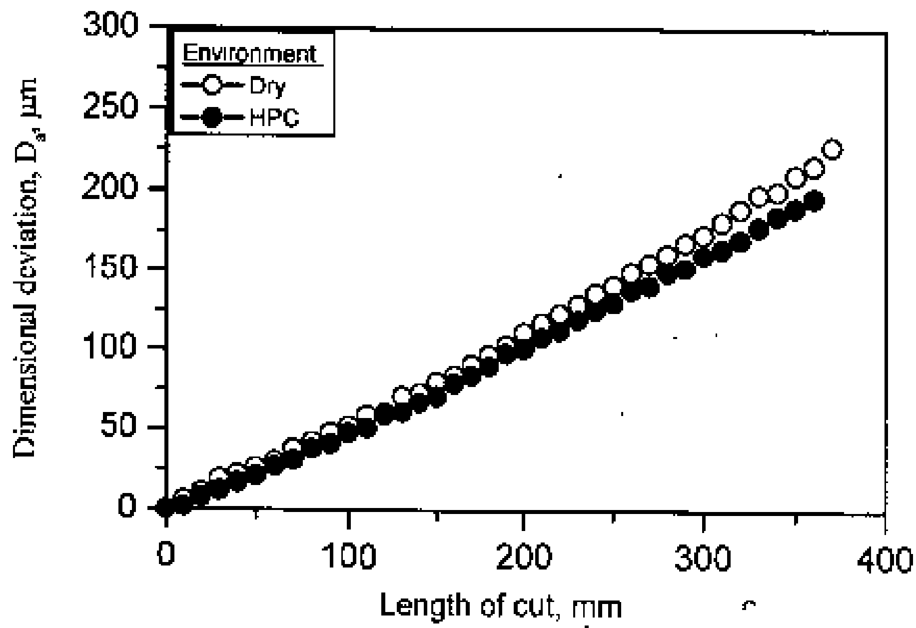
During straight turning in a centre lathe, the diameter of the machined part is gradually found to (1) increase along length of cut due to gradual wear of the tool tip (2) decrease due to thermal expansion and subsequent cooling of the job if the job temperature rises significantly during machining and (3) increase due to system compliance of the machine-fixture-tool-work system under the action of the cutting forces.

The order of dimensional deviations possible due to thermal expansion of the job even under dry machining and due to compliance of machine-fixture-tool-work piece system were calculated for the steel specimens being machined under the present conditions and the values appear to be extremely small compared to that possible due to wear of the tool tips. Therefore, in the present study, the dimensional deviations are considered to be mainly due to wear of the tool tips.

The variation in diameter of the job was precisely measured along its axis after one full pass of the machining over 600 mm length with full depth, at reasonably high feed and cutting velocity suitable for the tool- work-environment combinations undertaken keeping the initial diameter and the length of the steel rods same and uniform as far as possible. The gradual increase in dimensional deviations one full pass of machining at cutting velocity 154 m/min, 1.0 mm depth of cut and 0.14 mm/rev feed under dry and HPC cooling condition in fig 4.14 (a) and 4.14 (b).



(a)SNMG insert.



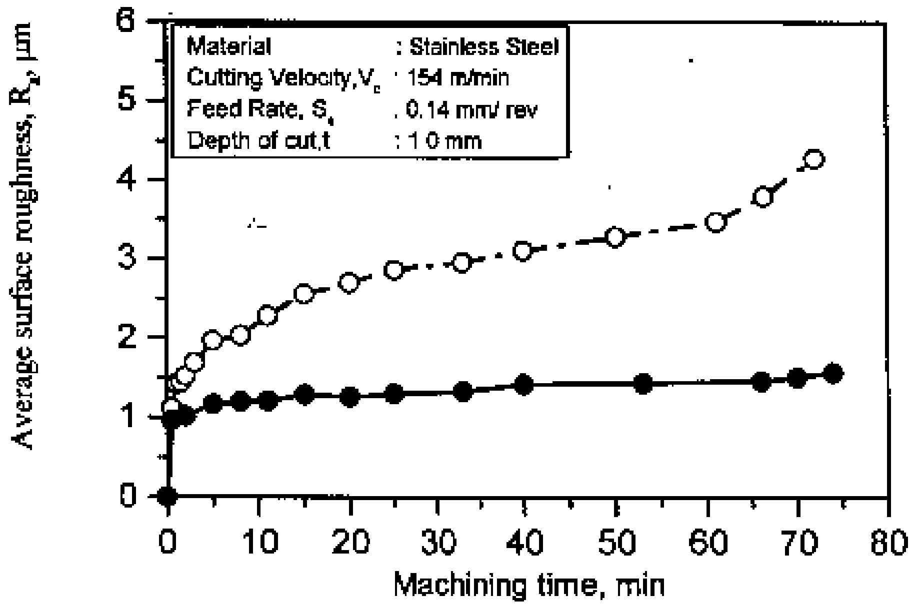
(b)SNMM insert.

Fig. 4.14 Variation in deviation of dimension with length of cut under dry and HPC conditions.

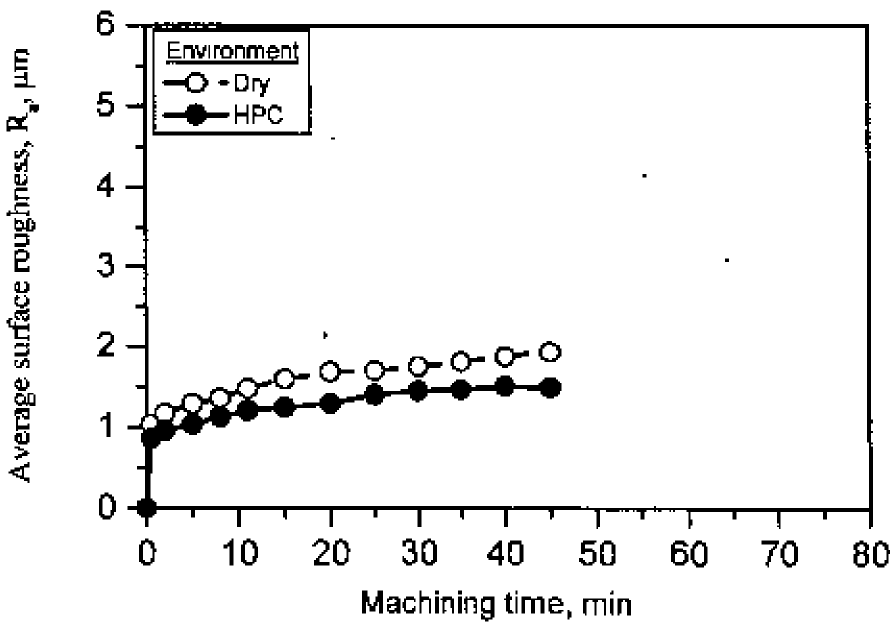
The performance and service life of any machined part are governed largely by quality of that product, which for a given material is generally assessed by quality of that product, in respect of surface roughness, oxidation, corrosion, residual stresses and surface and subsurface micro cracks.

Therefore, surface finish is an important index of machinability because performance and service life of the machined component are often affected by its surface finish, nature and extent of residual stresses and presence of surface or subsurface micro-cracks, if any, particularly when that component is to be used under dynamic loading or in conjugation with some other mating part(s). Generally, good surface finish, if essential, is achieved by finishing processes like turning but sometimes it is left to machining. Even if it is to be finally finished by turning, machining prior to that needs to be done with surface roughness as low as possible to facilitate and economize the turning operation and reduce initial surface defects as far as possible. . On the other hand, 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
iv. Built-up edge formation, if any.



(a) SNMG insert



(b) SNMM insert

Fig. 4.15 Variation in average surface roughness, Ra with machining time under dry and HPC conditions.

The variation in surface roughness observed with progress of machining of stainless steel by the SNMG and SNMM insert at a particular set of cutting velocity, V_c, feed rate, S_o and depth of cut, t under dry, and HPC conditions have been in shown in Fig4.15 (a) and 4.15 (b).

Chapter-5

Result & Discussion

5.1 Cutting Temperature

The application of HPC at chip tool interface is expected to improve upon the aforesaid machinability characteristics that play vital role on productivity, product quality and overall economy in addition to environment-friendliness in machining particularly when the cutting temperature is very high.

The average chip-tool interface temperature, T has been determined using the tool work thermocouple technique and plotted against cutting velocity for different feeds and environments undertaken. The Fig.4.5 (a) and 4.5 (b) is showing the effect of HPC on average chip-tool interface temperature, T under different cutting velocity, V_c and feed rate, S_o as compared to dry and HPC conditions. However, it is clear from the afore mentioned figures that with the increase in V_c and S_o, average chip-tool interface temperature, T increased as usual, even under HPC condition, due to increase in energy input.

The roles of variation of process parameters on percentage reduction of average interface temperature due to HPC have not been uniform. This may be attributed to variation in the chip forms particularly chip-tool contact length, which for a given tool widely vary with the mechanical properties and behaviour of the work material under the cutting conditions. The value of Chip-tool contact length affects not only the cutting forces but also the cutting temperature. In the present project also the value of chip-tool contact length had to be incorporated as the span of heat input at the chip-tool interface. Post cooling of the chips by HPC jet is also likely to influence T to some extent depending upon the chip form and thermal conductivity of the work materials.

However, during machining at lower V_c when the chip-tool contact is partially elastic, where the chip leaves the tool, HPC is dragged in that elastic contact zone in small quantity by capillary effect and is likely to enable more effective cooling. With the increase in V_c the chip makes fully plastic or bulk contact with the tool rake surface and prevents any fluid from entering into the hot chip-tool interface. As shown in Fig.4.5 (a) and fig 4.5 (b), HPC cooling effect also improved to some extent with the decrease in feed particularly at lower cutting velocity. Possibly, the thinner chips, especially at lower chip velocity, are slightly pushed up by the HPC jet coming from opposite direction and enables it come closer to the hot chip-tool contact zone to remove heat more effectively. Further, at high cutting velocity, the coolant may not get enough time to remove the heat accumulated at the cutting zone resulting in less reduction in temperature under HPC condition. With the increase in feed rate, S_o, shown in Fig.4.5 (a) and 4.5 (b), the chip-tool contact length generally increases but the close curvature of the grooves parallel and close to the cutting edges of the insert has reduced the chip-tool contact length and thus possibly helped in reducing the chip-tool interface temperature further. However, it was observed that the HPC jet in its present way of application enabled reduction of the average cutting temperature by about 5% to 10% depending upon the levels of the process parameters, V_c and S_o. Even such apparently small reduction in the cutting temperature is expected to have some favourable influence on other machinability indices.

5.2 Tool Wear

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 gradually 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 surface 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 (V_B) of its principal flank wear reaches a limiting value, like 0.3 mm.Therefore, attempts should be made to reduce the growth of flank wear (V_B) in all possible ways without much sacrifice in MRR.

Fig 4.6 (a), 4.6 (b), 4.7 (a) and 4.7 (b) shows the growths of average principal flank wear, V_B and maximum principal flank wear V_M on the main cutting edge under dry and HPC conditions. The gradual growth of average principal flank wear, V_B and maximum principal flank wear V_M, the predominant parameter to ascertain expiry of tool life, observed under all the environments indicates steady machining without any premature tool failure by chipping, fracturing etc. establishing proper choice of domain of process parameters. Fig. 4.6 (a), 4.6 (b), 4.7 (a) and 4.7 (b) clearly shows that principal flank wear V_B and V_M particularly its rate of growth decreased by HPC. The cause behind reduction in V_B and V_M observed may reasouably be attributed to reduction in the flank temperature by HPC, which helped in reducing abrasion wear by retainiug 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 HPC is properly applied.

Figure 4.6 (a), 4.6 (b), 4.7 (a) and 4.7 (b) clearly shows that flank wear, V_B and V_M particularly its rate of growth decreased substantially by high–pressure cooling. Crater wears of carbide tools in machining steels particularly at higher V_c and S_o adhesion and diffusion also come into picture due to intimate contact with the work surface at the elevated temperature.

The cause behind reduction in V_B and V_M observed may be reasouably be attributed to substantial reduction in the flank temperature by high pressure cooling particularly the jet impinged along the main cutting edge, which helped in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion type of wears which are sensitive to temperature. Because of such reduction in rate of growth of flank wear the tool life would be much higher if high pressure cooling is properly applied.

By using SNMG insert average principal flank wear is higher than the using of SNMM insert in dry and HPC condition. Possibly, this result come for more heat generation at the primary deformation zone due to shear and plastic deformatiou, chip-tool interface due to secondary deformation and sliding. There may be more work-tool interfaces due to rubbing.

Another important tool wear criteria are average auxiliary flank wear, V_S and maximum auxiliary flank wear V_{SM} which governs the surface finish on the job as well as dimensional accnracy. Irregular and higher auxiliary flank wear leads to poor surface finish and dimensional inaccuracy.

The growth of auxiliary flank wear, V_S and V_{SM} has been depicted in Fig.4.8 (a), 4.8 (b), 4.9 (a) and 4.9 (b) for all the trials undertaken. The nature of growth of auxiliary flank wear, V_S and V_{SM} matches with that of V_B and V_M expectedly. It appears from Fig. 4.8 (a), 4.8 (b), 4.9 (a) and 4.9 (b) that auxiliary flank wear (V_S) and maximnm auxiliary flank wear (V_{SM}) has also decreased during HPC machining. Fig4.6 (a & b), 4.7 (a & b), 4.8 (a & b) and 4.9 (a & b) clearly shows the amount of both principal flank wear and auxiliary flank wear after machining and depicts beneficial role of HPC, which is expected to provide better surface finish and dimensional accuracy.

It appears from Fig.4.8 (a), 4.8 (b), 4.9 (a) and 4.9 (b) that auxiliary flank wear (V_S) has also decreased during HPC machining. Fig.4.6(a), 4.6(b), 4.7(a), 4.7(b), 4.8(a), 4.8(b) and 4.9(a), 4.9 (b) clearly shows the amount of both principal flank wear and auxiliary flank wear after machining and depicts beneficial role of HPC, which is expected to provide better surface finish and dimensional accuracy.

By using SNMG insert average auxiliary flank wear is higher than the using of SNMM insert in dry and HPC condition. Possibly, this result comes for more heat generation. This may also occur by chip-tool interface due to secondary deformation and sliding.

Under all the environments, abrasive scratch marks appeared in the flanks. There have also been some indications of adhesive wear in the insert. Severe groove wear at the flank surfaces were found in insert under dry and HPC conditions. Some plastic deformation and micro chipping were found to occur under dry machining. Effective temperature control by HPC almost reduced the growth of groove wear on the main cutting edge as well as auxiliary cutting edges. Further the Fig4.6 (a & b), 4.7 (a & b), 4.8 (a & b) and 4.9 (a & b) clearly shows reduced principal flank wear and auxiliary flank wear under HPC condition.

Although auxiliary flank wear (V_s), though occurs less intensively, it also plays significant role in machining by aggravating dimensional inaccuracy and roughness of the finished surface. It appears from fig. 4.8 (a & b) and 4.9 (a & b) that auxiliary flank wear has also decreased sizably due to high pressure cooling.

5.3 Dimensional Deviation

It has been mentioned earlier that the diameter in straight turning of long rods may deviate from the theoretically expected value due to progressive wear of the tool-tip, variation of compliance of the M-F-T-W system along the axis of lathe and thermal expansion or distortion of the job, if much heated. The substantial reduction in dimensional deviation observed in the present investigation can be reasonably attributed mainly to reduction in the auxiliary flank wear of the inserts by HPC.

It can be noted that in fig.4.14 (a) and 4.14 (b) dimensional deviation increases with the increases of length of the job for both dry and HPC cooling. By applying high pressure cooling it is comparatively less. Fig. 4.14 (a) and 4.14 (b) also shows that for dry and high pressure cooling dimensional deviation increase with the increase of the length of the job. The dimensional deviation is less in high pressure cooling condition compared to dry machining by using both inserts due to much lesser break in wear or initial wear and absence of notching at the anxiliary flank of the insert.

From experimental findings, we see that SNMM insert dimensional deviation is higher than the using of SNMG insert. Careful observation of the figures presenting dimensional deviations under varions machining conditions and those presenting average flank wear visualizes that dimensional deviation observed have close relation with corresponding auxiliary flank wear.

5.4 Surface Roughness

The quality of any machined product of given material is generally assessed by dimensional accuracy and surface integrity, which govern the performance and service life of that product. For the present study, only surface finish has been considered for assessment of quality of product under dry, HPC machining.

The variation in surface roughness observed with progress of machining of stainless steel by the SNMG insert at a particular set of cutting velocity, V_c, feed rate, S_o and depth of cut, t under dry, HPC conditions have been in shown in fig.4.15 (a) and 4.15 (b). As HPC reduced average auxiliary flank wear and produced no notch wear on auxiliary cutting edge, surface roughness also grew very slowly under HPC conditions. Conventionally applied cutting fluid did not reduee tool wear compared to dry machining. But the surface roughness deteriorated drastically under wet machining compared to dry, which may possible be attributed to electrochemical interaction between insert and work piece. It appears from fig.4.15 (a) and 4.15 (b) that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips. HPC appeared to be effective in reducing surface roughness. 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.

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From fig.4.15 (a) and 4.15 (b); we see that SNMM insert surface roughness is higher than the using of SNMG insert. Careful observation of the figures presenting surface roughness under various machining conditions and those presenting average flank wear visualizes that surface roughness observed have close relation with corresponding auxiliary flank wear. This result may also occur due to rapid gradual wear of the SNMM tool tip due to system compliance of the machine-fixture-tool-work system under the action of cutting forces.

Chapter-6

Conclusion

This study led to the evaluation of the effectiveness of high-pressure coolant in machining stainless steel with coated carbide (TiCN + Al_2O_3) insert. The results clearly indicate the advantages of using high-pressure coolant over dry machining while machining stainless steel.

i. High-pressure coolant enabled sizable reduction in the cutting zone temperature and favorable change in the chip tool and work tool interactions, which helped in reducing friction, built-up edge formation and thermal distortion of the work.

ii. Application of high-pressure coolant through the tool rake surface reduces the friction at the tool chip interface due to formation of a cushion layer, which prevents intimate contact at the tool-chip interface.

iii. High-pressure coolant with the present technique has substantially reduced flank wear and hence is expected to improve tool life.

iv. The surface finish obtained with the use of high-pressure coolant is much better than that obtain in the case of dry machining. Under certain conditions, the surface finish obtained with the use of high-pressure coolant is comparable to that obtained in the case of turning operation.

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