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EFFECT OF HIGH PRESSURE COOLANT ON CHIP, ROUNDNESS DEVIATION AND TOOL WEAR IN DRILLING AISI-4340 STEEL

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ABSTRACT

Hole making had long been recognized as the most prominent machining process, requiring specialized techniques to achieve optimum cutting condition. Drilling can be described as a process where a multi-point tool is used to remove unwanted materials to produce a desired hole. It broadly covers those methods used for producing cylindrical holes in the work piece. However, high production machining and drilling with high cutting velocity, feed 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. In this case, high-pressure coolant (HPC) is very effective to reduce temperature. When temperature is increased a large amount of tool wear appears at the drill bit. In this situation, high temperature either affects roundness of the hole or chip shape and color of chip. HPC is applied in the same direction as the drill bit. HPC has reduced temperature as well as improving roundness and also provide lubrication in the tool tip and surface interface.

Keywords: High-pressure coolant (HPC), drilling, chip, roundness, taper and tool wear.

INTRODUCTION

The growing demand for higher productivity, product quality and overall economy in manufacturing by machining, grinding and drilling, 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 and grinding with high cutting velocity, feed 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 finish of the product.

Hole making had long been recognized as the most prominent machining process, requiring specialized techniques to achieve optimum cutting condition. Drilling can be described as a process where a multi-point tool is used to remove unwanted materials to produce a hole. It broadly covers those methods used for producing cylindrical holes in the work piece. 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 drilling operation is transformed into heat leading to conditions of high temperature and severe thermal/frictional conditions at the tool- chip interface [1].

During the drilling process, the most important factor affecting the cutting tool performance and work piece properties is cutting temperature that emerges between drill bit and chip [2,3]. The temperatures associated with the drilling process are particularly important, because drilling is one of the predominant industrial machining processes and heat effects in drilling are generally more severe than in other metal cutting operations. Drills often experience excessive temperatures because the drill is embedded in the work piece and heat generation is localized in a small area. The resulting temperatures can lead to accelerate tool wear and reduce tool life [4-6] and they can have profound effects on the overall quality of the machined work piece. Drill designers often select the geometrical features of a drill based on the expected temperature profile in the drill point, so accurate prediction of the temperature distribution is imperative [4]. Temperature not only be exaggerated the tool wear but also affect the surface, hole quality and chip formation. The cutting temperature directly influences hole sensitivity, surface roughness, and tool wear [3].

Worn drills produce poor quality holes and in extreme cases, a broken drill can destroy almost all finished part. A drill begins to wear as soon as it is placed into operation. As it wears, cutting forces will increases, the temperature of the drill rises and this accelerates the physical and chemical processes associated with drill wear and therefore drill wears faster [6]. Thrust and torque depend upon drill wear, drill size, feed rate and spindle speed. Research results shows that tool breakage, tool wear and work piece deflection are strongly related to cutting force [6].

In drilling, the material is removed in the form of chips and evacuated through the drill flutes. It has been demonstrated [7-9] that smaller chips are more easily removed from the drill by the action of the flutes, centrifugal forces, and/or metal working fluids. Long chips can become tangled around the drill, can lead to poor hole quality and are more difficult to manage once outside the hole thereby increasing production costs and lowering productivity. Furthermore, while drilling deep holes friction between the drill flutes and chips causes the chips to be evacuated slower than chips are produced. This leads to chip clogging, which in turn causes sudden increases in torque and thrust that may cause drill breakage. Improving chip evacuation will lead to less

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drill breakage, lower production costs, better hole quality, and increased productivity [10].

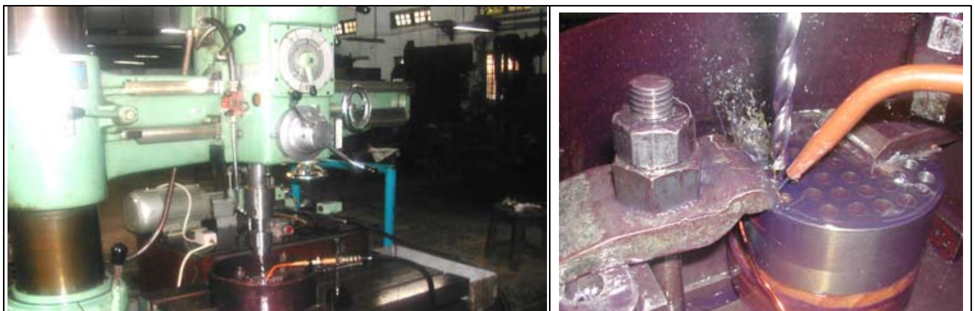
Currently in industries, this high temperature problem is partially tried to be controlled by reducing heat generation and moving heat from the cutting zone through optimum selection of machining parameters and geometry of the cutting tools, proper cutting fluid application and using heat resistant cutting tool materials like carbides, coated carbides and high performance ceramics (CBN). The thermal deterioration of the cutting tools can be reduced by using CBN tools [5]. If properly manufactured, selected and used, CBN tools provide much less cutting force, temperature and hence less tensile residual stress[11] .Though CBN tools are extremely heat and wear resistive, those are too expensive and are justified for very special work materials and requirements where other tools are not effective [1].

The application of cutting fluid during machining operation reduces cutting zone temperature and increases tool life and acts as lubricant as well [12]. It reduces cutting zone temperature either by removing heats as coolant or by reducing the heat generation as lubricant. In addition, it serves a practical function as a chip-handling medium [13]. However, it has been experienced [13] 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 in evident. 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 [2]. 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.

High-pressure jet of conventional coolant has been reported to provide some reduction in cutting temperature [14, 15] Cutting fluids have the dual tasks of cooling the cutting surface and flashing chip. 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 powerful stream that can reach onto the cutting area, provides strong chip removal and in some cases, enough pressure to deburr [15]. 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% [16]. Mazurkiewicz [17] 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 extant. The main objective of the present work is to make a experimental investigation on the role of high pressure coolant in drilling AISI-4340 steel with HSS drill and overall benefits in respects of cooling capacity of the fluid, chip, roundness deviation of the hole, taper of the hole and tool wear.

EXPERIMENTAL INVESTIGATION

Machining ferrous metals by high speed steel (HSS) is a major activity in the machining industries. Machining of steels involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip-tool contact. Again, the cutting temperature increases further with the increase in strength and hardness of the steels for more specific energy requirement. Keeping these facts in view the commonly used steel like AISI-4340 steel has been undertaken for the present investigations. Considering common interest and time constraint, only HSS have been used for the present investigation. Wide scope will remain for further study on high-pressure coolant (HPC) effect in drilling steels by HSS and exotic materials by high performance drill bit. The drilling tests have been carried out by drilling of AISI-4340 steel on a drill machine (R915L Drill Machine, Italy) by HSS drill under dry and high pressure coolant conditions. The positioning of the nozzle tip with respect to the HSS drill has been settled after a number of trials. The photographic view of the experimental set-up is shown in Figure-1 and the conditions under which the machining tests were carried out are briefly given in Table-1.



Nozzle injected HPC

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

Table-1. Experimental conditions.

Machine tool	:	R915L (30-40) Drill Machine, Italy, 3.7 kW
Work material	:	AISI-4340[C-0.36%, Mn-0.92%, Ni-2.85%, Cr-1.41%, Mo-0.52%, V-0.2%]
Cutting tool	:	High speed steel (HSS), diameter: 10 mm
Process parameters		
Cutting velocity, Vc	:	30.75 m/min
Feed rate, So	:	0.10 mm/rev
Depth of cut, t	:	40.00 mm
Cutting oil	:	HC Straight run, VG 68
HPC supply	:	Pressure: 40 bar, Coolant: 6 l/min through external nozzle having 1.0 mm tip diameter.
Environment	:	Dry and High Pressure coolant (HPC) condition

The diameter and roundness deviation of the holes were measured by a digital slide calipers. After drilling operation the drill bit was examined under scanning electronic microscope (SEM).

The cooling capacity of the cutting oil (HC Straight run, VG 68) at different pressure and flow rate used in this experiment is important. They were found out using an electric furnace. The maximum temperature measured in the middle of the work piece was 400°C, obtained after keeping it inside the furnace for a period of 8 minutes. After heating, the work pieces were submitted to cooling condition similar to the experiments, i.e. high-pressure coolant condition at different pressure. The temperature was measured by a K-type thermocouple for eight minutes.This thermo-sensor was connected to the work piece through a hole that allowed it to reach the center of the work piece. The hose of fluid was in a distance of 15mm from the upper part of the work piece. The cooling capacity of the fluid at different pressure is shown in Figure-2. It is evident from Figure-2 that the cooling capacity of the cutting oil is more at 40 bars so the experiment was carried out at coolant pressure of 40 bar.

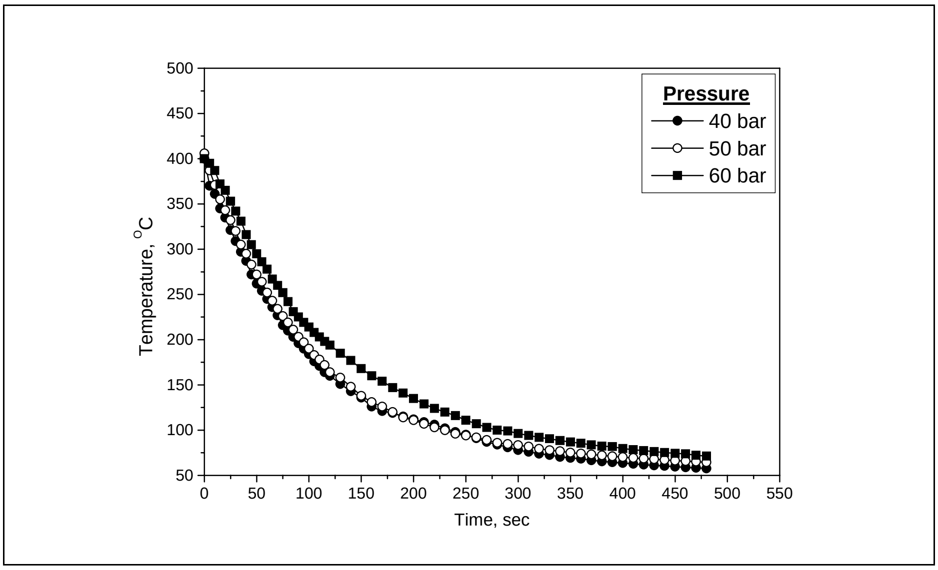


Figure-2. Cooling capacity of the fluids used in the experiments.

RESULTS AND DISCUSSION

Chip shape is the most important factor for the smoothness of a drilling process. The drilling process will be smooth if chips are well broken. However, most ductile materials do not break during drilling, and instead, form continuous chips.

Based on the chip forming mechanisms, continuous chips can be categorized to spiral chips and string chips. When chips are initially generated, because the inner cutting edge moves significantly slower than the outer cutting edge, the inner chip is inherently shorter than the outer chip. This difference in length within the chip forces it flow to the drill center instead of perpendicular to the cutting edge. Furthermore, the center part of the drill flute forces the chip to curl and form a spiral shape. However, when spiral chips move in the drill flute, in order to maintain its spiral shape, they have to constantly rotate on their own axis.This rotational motion causes the spiral chips to have difficulty maintaining their shape as the hole gets deeper. If chips

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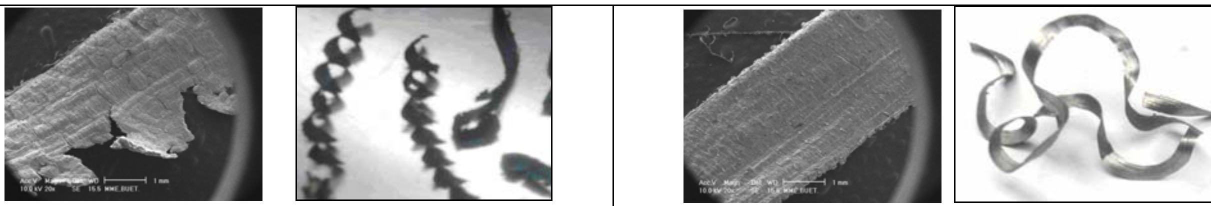
cannot keep up with the rotational motion, they will either break or be forced to move along the flute without spinning, and form string chips.

High-pressure coolant (HPC) played very effective role for cooling and provided lubrication between drill bit and chip interface. Figure-3 shows the condition of chips during drilling steel by HSS drill bit under both dry and high-pressure coolant (HPC) condition. The shape of the chip produced under dry conditions was spiral but under high-pressure coolant condition became string. The color of the chips became lighter i.e. metallic from burnt blue due to reduction in drilling temperature by high-pressure coolant condition.



(a) Dry condition (b) High-pressure coolant condition

Figure-3. SEM views of chips produced while drilling steel by HSS drill bit under (a) dry and (b) high-pressure coolant condition.

Before the analysis of the quality parameters of the holes, it is important to note that neither diameter nor any other quality parameter of the hole was influenced by tool wear. In other words, these parameters presented no tendency as feed length increased. Table-2 shows the average, maximum and minimum diameters measured in the first third part of the hole length in both dry and HPC lubrication systems. It can be observed that the standard deviation of average diameter obtained under HPC conditions is lower than that obtained using dry condition, which means that the HPC presented a better quality.

Table-2. Diameter close to the entrance and end of the hole.

Lubrication System	**Diameter close to the entrance of the hole**				**Diameter close to the end of the hole**			
	$D_{maximum}$ (mm)	$D_{minimum}$ (mm)	$D_{average}$ (mm)	**Standard deviation**	$D_{maximum}$ (mm)	$D_{minimum}$ (mm)	$D_{average}$ (mm)	**Standard deviation**
Dry	10.094	10.045	10.075	0.01588	10.046	10.012	10.030	0.008044
HPC	10.072	10.031	10.051	0.01105	10.054	10.031	10.041	0.007521

Figures 4 and 5 show the roundness of the holes close to the entrance while Figures 6 and 7 show the roundness of the holes close to the end of the holes, respectively obtained during drilling the steel. It can be seen from these figures that the roundness deviation did not change appreciably from the beginning to the end of the holes under HPC condition in compare to dry condition. This result can be attributed to the lower cutting forces and the shorter diameters. Even with the drill penetrating further into the hole, the forces were not able to deviate the drill more than in the entrance of the hole, and the roundness deviation was kept almost constant. The roundness deviation was smaller at both the entrance and end of the holes under HPC condition in compare to dry condition, because of high lubricant capacity.

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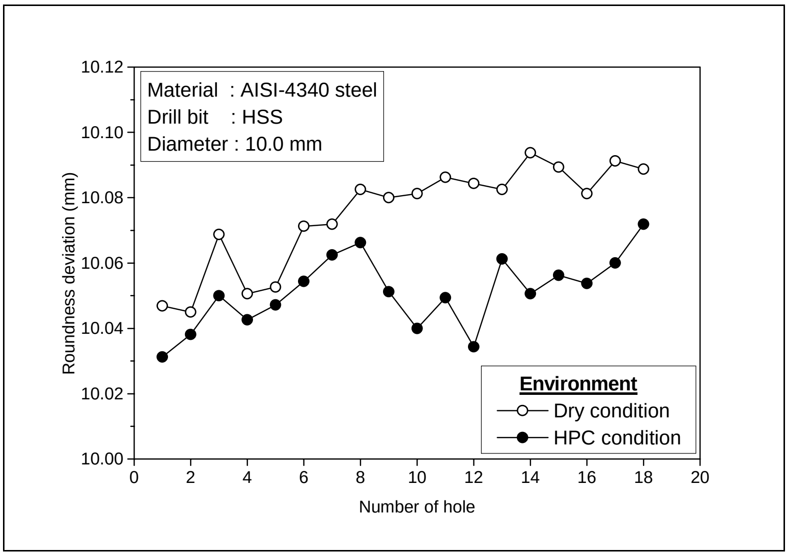

Figure-4. Roundness deviation close to the beginning of holes under dry and high-pressure coolant conditions.

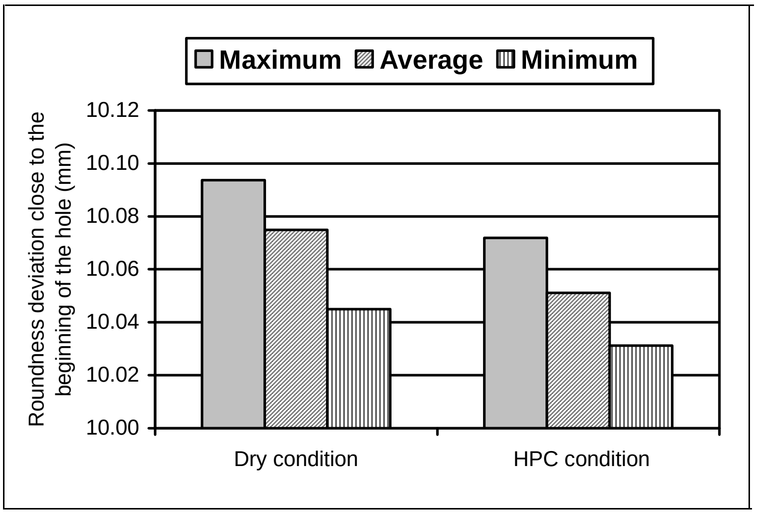

Figure-5. Roundness deviation of maximum, average and minimum value close to the beginning of holes under dry and high-pressure coolant conditions.

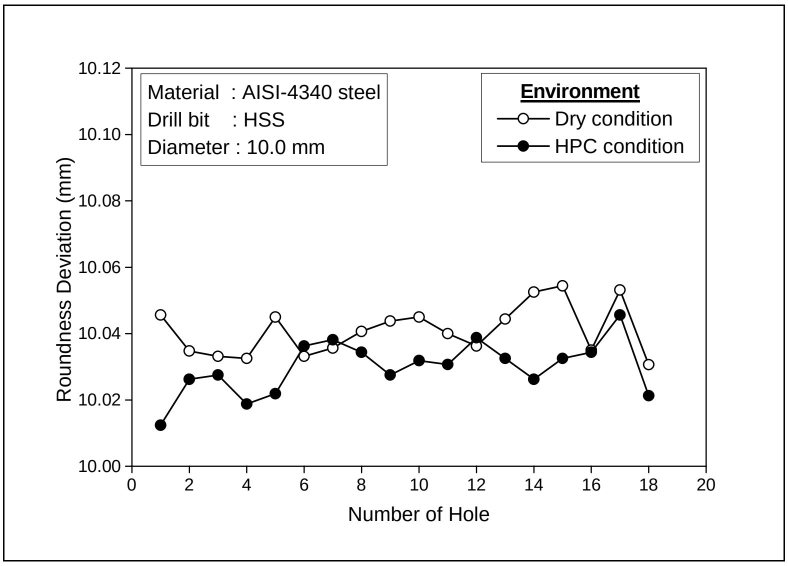

Figure-6. Roundness deviation close to the end of holes under dry and high-pressure coolant conditions.

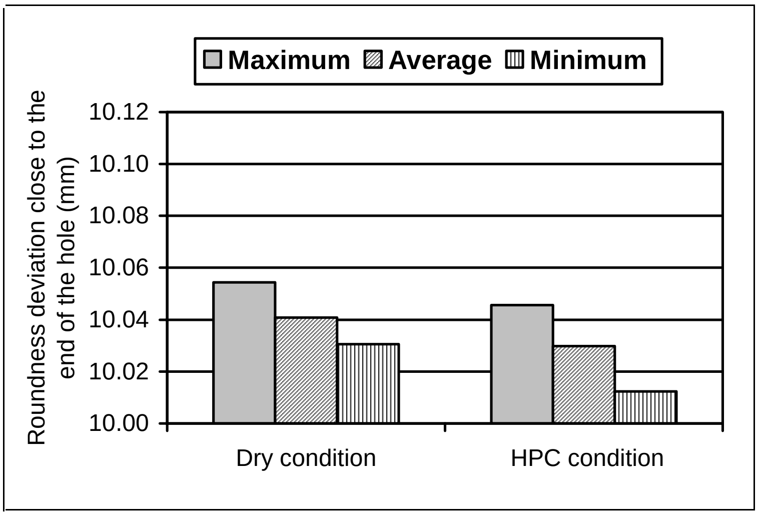

Figure-7. Roundness deviation of maximum, average and minimum value close to the end of holes under dry and high-pressure coolant conditions.

Figures 8 and 9 show the taper values under dry and high-pressure coolant condition. The average taper values and their dispersion were smaller under high-pressure coolant condition. Moreover, in both conditions the average taper values were positive, i.e., the diameters in the entrance of the holes were bigger than at the end. These bad results found for the holes made under dry condition are due lack of lubrication action, which made the diameter in the beginning of the holes to increase.

When the tool reached the end of the holes, the diameter decreased, due to the alignment of the tool caused by the hole wall. When high depth of cut is used, the drilling using dry condition is not possible because of high tool wear. The SEM views of the worn out drill bit is shown in Figure-10. Moreover, the quality of the holes obtained using high-pressure coolant is much better than that obtained using dry condition.

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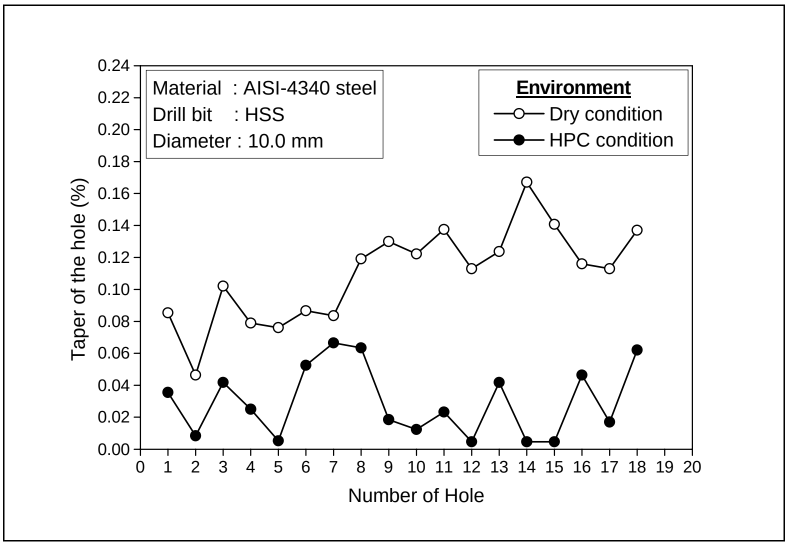


Figure-8. Variation of diameter deviation with number of holes under dry and HPC conditions.

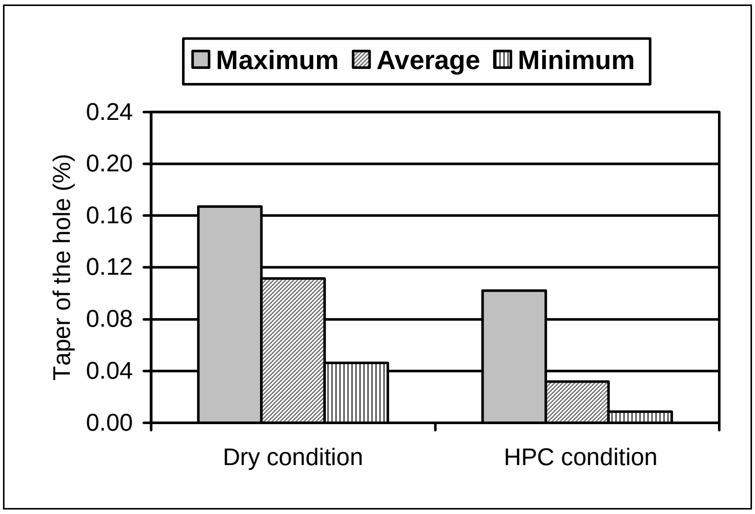
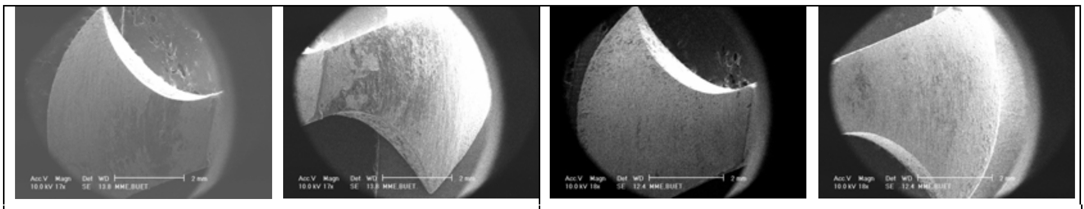


Figure-9. Taper values of maximum, average and minimum under Dry and HPC conditions.



(a) Dry condition | (b) High-pressure coolant condition

Figure-10. SEM view of drill bit under (a) dry (b) high pressure coolant condition.

CONCLUSION

The experimentally observed role of high-pressure coolant (HPC) in drilling AISI-4340 steel by HSS drill may be summarized as follows:

- The formation of chip under HPC condition is more favorable in compare to dry condition because of high lubricant capacity.
- Roundness deviation was smaller at both the entrance and end of the holes under HPC condition in compare to dry condition. When high depth of cut used, the drilling with dry condition was not possible because of poor cooling and lubrication action.
- Taper values and their dispersion were smaller under high-pressure coolant condition.

Moreover, in both conditions the average taper values were positive i.e., the diameters in the entrance of the holes were bigger than at the end.

- The beneficial effects of HPC may be attributed to effective lubrication action, which prevents the chip sticking on the tool and makes the cut feasible.

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