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Machining performance analysis of Turning of Inconel 718 under different coolant environment

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The current aerospace industry demands materials with superior mechanical, thermal, chemical, and physical properties with lesser weights. Nickel-based alloys particularly Inconel 718 have many applications in the aerospace industry. Inconel is hard to cut metal alloy. In the current analysis turning experiments are carried on Inconel 718 under high-pressure coolant conditions, conventional flood cooling, and dry turning. With the above cutting environment analysis for forces, surface quality and wear of tool are carried out. Kistler cutting force dynamometers, High-resolution photography, and scanning electron microscopy are used asses cutting force, tool wear, and surface quality. A significant drop in cutting force, radial, and tool wear are observed at high-pressure coolant. High-pressure coolant and dry turning give better results for surface finish. In particular machining with high-pressure coolant can improve the performance of the turning operation of Inconel 718.

Keywords: Inconel 718, High-Pressure coolant, Surface roughness, Tool wear, Cutting forces

1 Introduction

The requirements of superior material to suit for aeronautical and automobile and other special applications are growing day by day globally. Particularly aerospace requires high performance metal alloys to work in very extraordinary working conditions. Heat resistance super alloys (HRSA) are very much suitable to work at high temperatures with where severe mechanical stresses[1]. HRSA in comparison with other metal alloys can give superior oxidation resistance, creep resistance and corrosion resistance even at elevated temperature. This makes them a perfect choice in aerospace engine components, gas turbines, and also in biomedical applications. Nickel base HRSA due to lighter weights and stronger nature are regularly used for aerospace components manufacture[2]. Inconel 718 is HRSA from nickel-chromium group and contains considerable amounts of niobium, iron, and molybdenum along with minor amounts of titanium and aluminum[3]. Its properties like superior strength at high temperature, corrosion resistance, exceptional weldability makes it suitable for special application in aircraft turbine engines, rocket engines, pumps, tooling, cryogenic and nuclear industries[4,5].

While machining difficult to cut metal alloys like Inconel 718 a due consideration must be given to selection of tool, its geometry, and material. Detailed investigations on the tool wear and tool life in turning as Inconel 718 are necessary. Work hardening effect during its machining is one the reason which contributes to tool wear[6].

Some of failure modes of tool while machining Inconel 718 are notch wear and flank wear[7,8,9], plastic deformation[8] , crater [9]. Sometimes severe thermal and mechanical stresses induced close to the cutting edge due its poor machinability[10]. Hao *et al.*[11] found lot of adhered material at cutting edge (built-up-edge) at low cutting speed of 20 m/min. Machining Inconel 718 with pressurized coolant leads to efficient chip breaking which usually extend the life of tool. Conventional cooling leads to slightly higher wear rate and more welding of work as compared to high pressure cooling[12].

Cutting forces acting on cutting tool during machining are amongst the very important parameters for economical cutting conditions[13]. Cutting forces form basis for determining cutting conditions, estimating power requirements, estimating the workpiece accuracy achievable under certain conditions and explaining wear mechanisms[14, 15]. Higher cutting speed may result in reduced cutting forces as compared to lower cutting speeds[16,17]. Cutting force can be decreased due ultrasonic-aided turning of Inconel 718[18]. Cutting speed is strongly

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connected to cutting force[19]. Fang and Wu [20] reported decrease in cutting force, thrust force and the result force with increase in cutting speed however Trend was opposite with increased feed. The force ratio increases with increase in feed as well as speed. Cutting forces can be radically lowered high pressure coolant [9,21,7].

Surface roughness is very important for component and it may affect the fatigue strength, and surface wear of machined components. For functional components the characterization surface texture is a challenging task[22]. Particularly for aerospace components to improve their life surface finish is very important aspect [23]. Increase in cutting speed may lower down surface roughness values in dry cutting but in wet conditions this happens only after 60 m/min[24]. Nalbant *et al.* [25] mentioned about a significantly different effect of single layer and multiple layer coated tools on the average surface roughness. They also reported suitability of round insert for surface roughness. Arunachalam *et al.*[26] reported decreasing trend of surface roughness with increase in the cutting speed. They also mentioned about significant effect of CBN insert geometries (round and square) and use of coolant on the surface roughness. Surface roughness can be improved with 80 bar coolant pressure[27].

A material to suit for aerospace application must possess variety of superior properties to endure intimidating environments. Lot of attention must be given to select proper machining environment during manufacturing theses aerospace components. Particularly during turning operation many machining environments are possible. There is need to see effect of various coolant conditions along with dry cutting on machining performance of Inconel 718. This paper presents a comparative analysis of machining of Inconel at different cooling conditions like Dry cutting, conventional coolant, and with high pressure coolant assisted turning at 20 bar, 50 bar and at 80 bar. Under these conditions tool wear, surface roughness, cutting forces are analyzed.

2 Materials and Methods

The details of machine, cutting tool, measurement and equipments used for current investigation with all possible details of experimental work are shown in Fig. 1. Experimental set up is shown in Fig. 2. In this

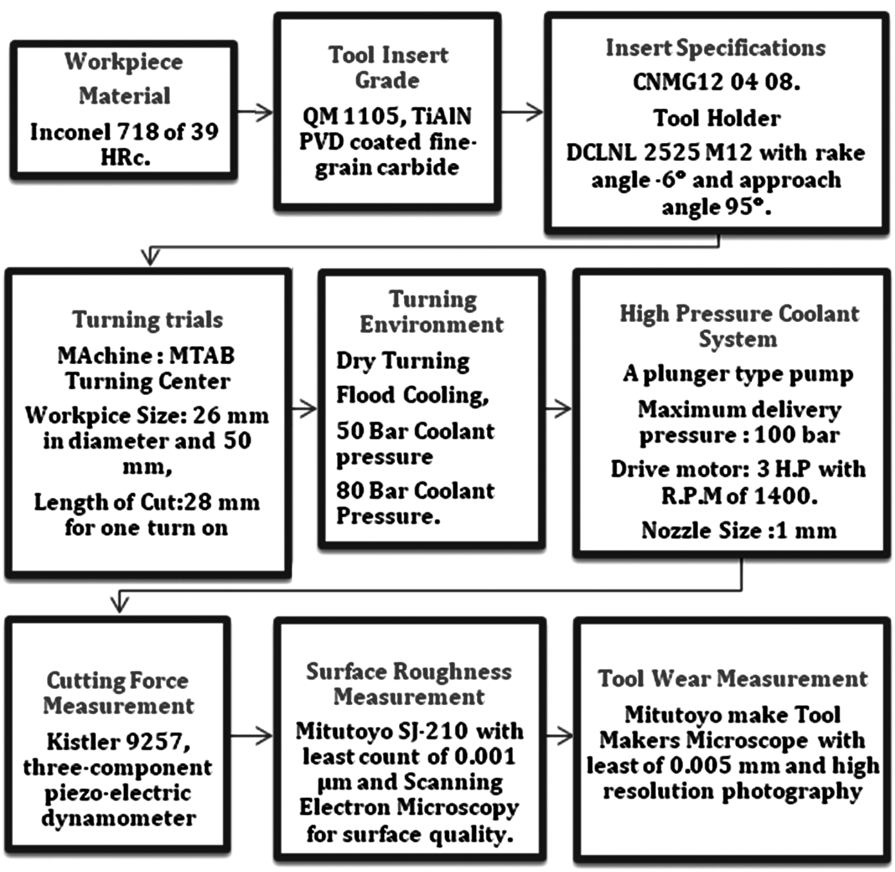


Fig. 1 — Experimental Theme.

investigation four types of cooling environments for turning operations are used. These are dry turning without any coolant, wet or flood coolant turning, turning with pressurized coolant at 50 bar with flow rate 4 liters per minutes and 80 bar with flow rate of 6 liters per minutes. While using high pressure coolant for turning Inconel 718 position of nozzle is very important to direct coolant at appropriate location in cutting zone.

Here coolant is directed in machining zone exactly at point where chip originates as shown in Fig. 3. In Fig. 3 coolant delivery position along with its CAD model is visible. Throughout the trials cutting speed is kept at 100 m/min, feed is kept at 0.2 mm/rev. and depth of cut is 1 mm. The length of cut is 28 mm for one cut. Tool wear is measured for the wear assessment after two cuts for first set and after one cut after that. The limit for tool wear is set at a flank wear of 0.3 mm (300µm). After machining high resolution photographs of tool are taken to view tool wear pattern.

After machining surface roughness is measured and for all machined component SEM images are taken for comparison of machined surface. Forces are recorded and variation in forces is also visible on computer display connected to dynamometer.

3 Results and Discussions

In following sections analysis after experimental work is presented with respect to tool wear, cutting force, surface roughness and surface quality.

3.1 Analysis of Tool Wear

Figure 4 indicates values and bar chart of tool wear values for different machining environments. Inconel is one of the difficult to cut metal alloy so during its machining toll wear rate is very fast. It is observed during dry machining that in the machining zone continuous flames are generated

This is indication of large amount of heat in machining zone.

These flame induce burn marks and cause rapid wear of tool, it can be seen in Fig. 5. A flank wear of 385µm and crater wear of 580 µm is recorded for an 84 mm turning length. Wet machining also gives poor

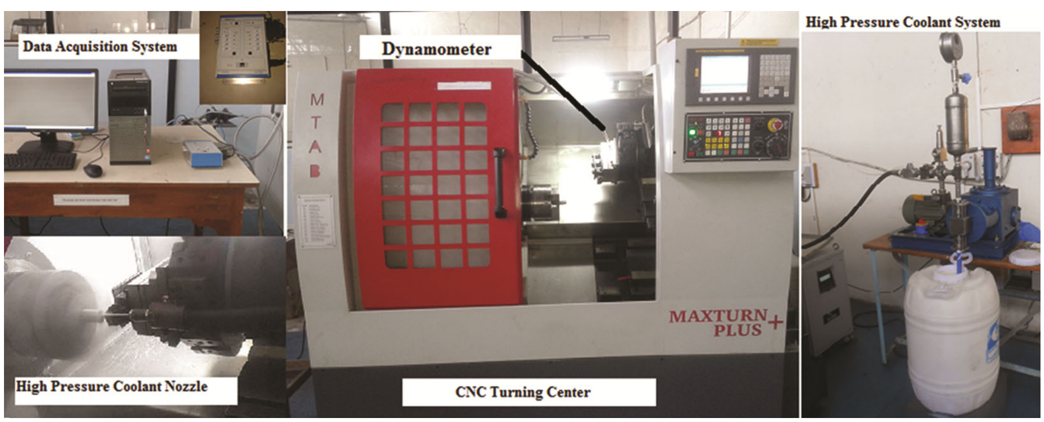


Fig. 2 — Experimental Set Up.

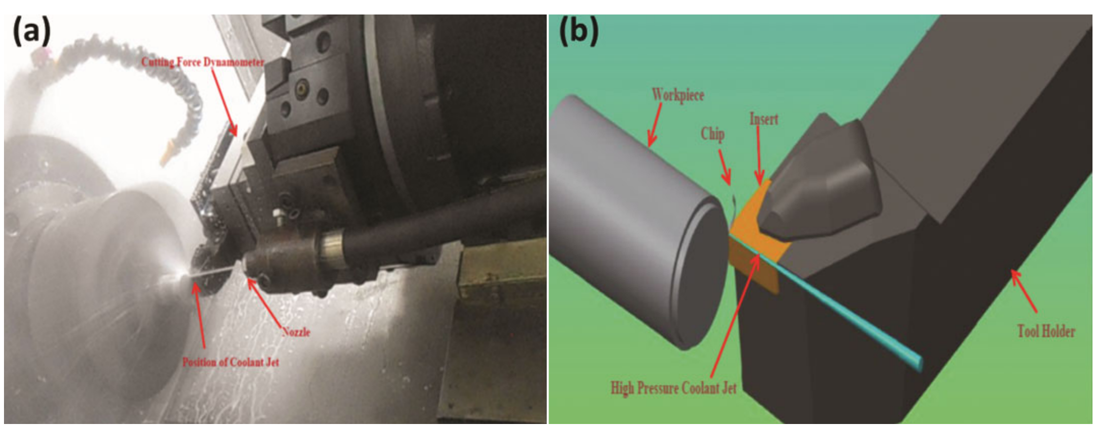


Fig. 3 — Nozzle position and 3D CAD model for nozzle position.

results as compared to high pressure assisted turning. In wet machining a flank wear of 325µm and crater wear of 485 µm is recorded for a 114 mm turning length and here last cut is taken with 0.5 mm depth of cut. In between high pressure coolant turning gives good results for tool wear. Flank wear of 345µm and crater wear of 550 µm is recorded for a 140 mm turning length for 50 bar coolant pressure. At 80 bar a flank wear of 305µm and crater wear of 410 µm is recorded for a 140 mm turning length. So at high pressures of 50 bar and 80 bar tool can turn almost double length as that of dry turning and wet turning.

This effect can be contributed to efficient chip control because of high pressure of coolant. During turning operation chips carry away almost 75% heat from machining zone. When these hot chips come in contact with tool surface they start wearing of tool because of friction. The above effect is minimized due to high pressure. High-pressure coolant not only curls the chip but also keeps them away from cutting zone by breaking them into small pieces. Because of high velocity of coolant, jet chips moves away from cutting zone as compared to conventional coolant. The curling of chip reduces the contact length of chips with tool. It is visible from Figs (5 and 6) that damage of tool is more in dry and wet, machining as compared to high pressure coolant assisted machining.

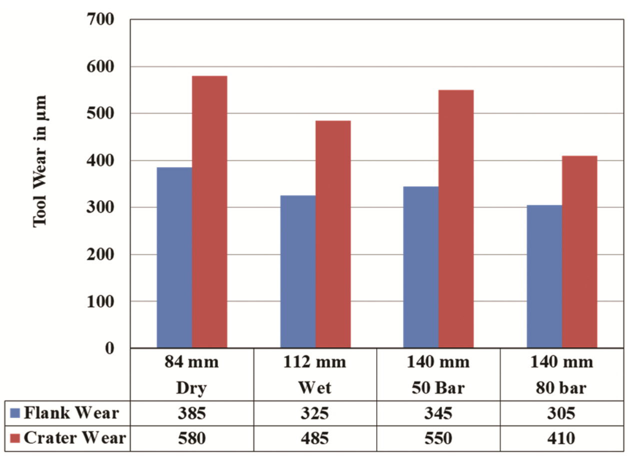


Fig. 4 — Tool Wear for Different Machining Environments.

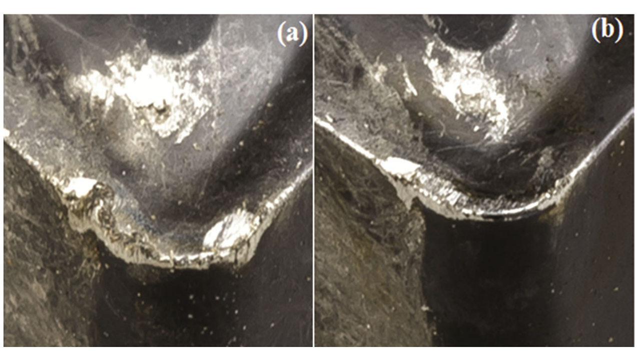


Fig. 5 — Tool Wear Pattern on Tool Nose (a) Dry Turning, and (b) Wet Turning.

3.2 Quality of Machined Surface

After machining surface roughness is measured and for all machined component SEM images are taken for comparison of machined surface.

Radar graph in Fig. 7 shows values of surface roughness at various machining environment. Figs (8-9) shows SEM images of machined surface for all machining environments respectively.

The variation and actual values of surface roughness clearly indicates that, with high coolant pressure of 80 bar, 50 bar and dry turning low values of surface roughness are observed which indicates a better surface finish while turning with wet environment.

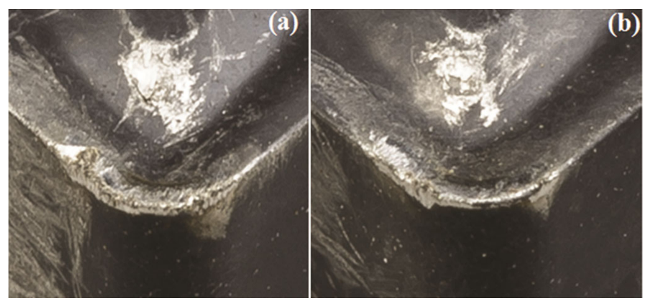


Fig. 6 — Tool Wear Pattern on Tool Nose (a) at 50 bar coolant pressure, and (b) 80 bar coolant pressure.

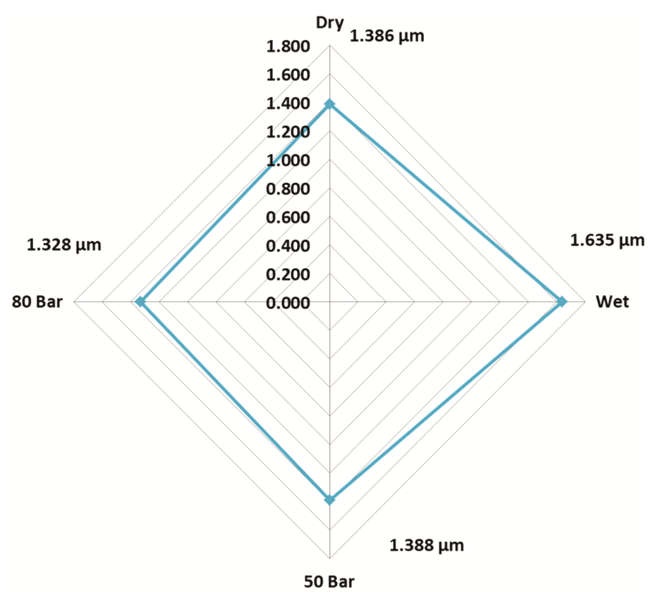


Fig. 7 — Surface Roughness Values and Variation at Different Machining Environment.

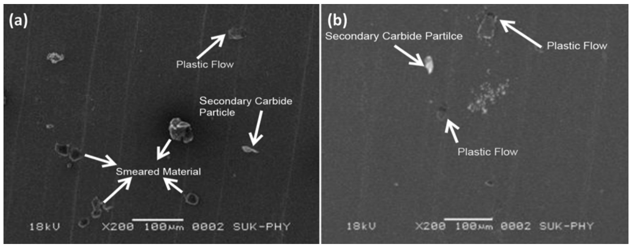


Fig. 8 — SEM Images for Dry Turning, and Wet Turning.

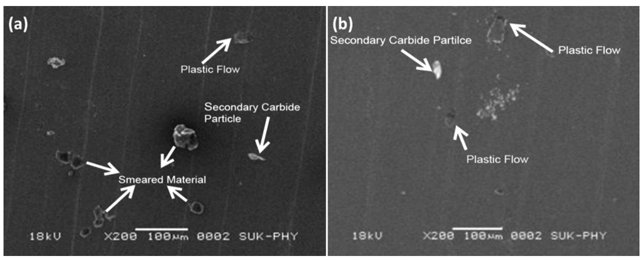


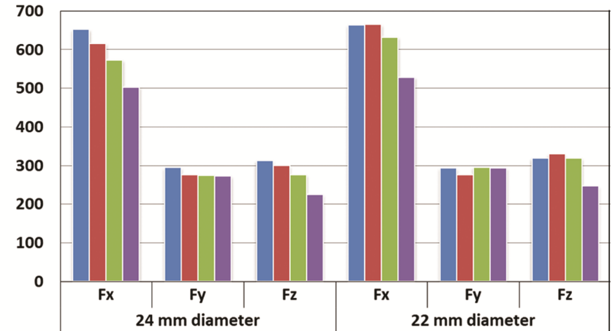
Fig. 9 — SEM Images for Turning at 50 bar coolant, and 80 bar coolant pressure.

It can be reported that an improvement of 18.77 % in surface roughness while machining at 80 bar as contrast to wet machining. Similarly an improvement of 4.18 % and 4.32 % in surface roughness with 80 bar as compared to dry and 50 bar coolant pressure machiningrespectively.SEM images of machined surface confirm that machining at high pressure i.e. at 80 bar and 50 bar pressure surface texture is very good with very few flaws. Only some traces of secondary carbide particles are observed at these high pressure coolant conditions.

While machining at conventional wet machining (at relatively low pressure of coolant) and dry machining many flaws like plastic flow, smeared material and secondary carbide particles are observed. At low pressure, these flaws occur mainly because of insufficient cooling leading to increase in temperature, which causes welding of either chips or tool material to machined surface. This indicates capability of high pressure coolant to produce a very good machined surface. This can be attributed to efficient cooling resulting in reduction in friction at secondary deformation zone.

3.3 Cutting Force Analysis

Fig. 10 shows the bar charts of recorded values of Cutting Force (Fx), Feed Force (Fy) and Radial Force (Fy) and for different machining environment machining for first to cut i.e from 26 mm to 24 mm and 24 mm to 22 mm. During these to cuts total turning done of Inconel 718 bars is 56 mm and From absolute values of Cutting Force (Fx), Radial Force



	24 mm diameter			22 mm diameter		
	Fx	Fy	Fz	Fx	Fy	Fz
Dry	651.5	294.4	312.1	663.5	293.1	318.4
Wet	615.9	275.5	299.6	664.8	276.3	329.3
50 Bar	572.7	274	275.9	632	295	318.7
80 Bar	502.7	272.4	224.7	528.4	293.9	246.4

Fig. 10 — Cutting Force Component Values at Different Environment for Two Cuts.

(Fy) and Feed Force (Fz) it can be clearly seen a big drop in all cutting force and radial force components when turning at high pressure coolant at 50 bar and 80 bar. Force components recorded at wet turning are also lower than dry machining. This trend is similar for all the cuts taken up to final wear of tool as mentioned in section 3.1.

For first length of cut that is while turning from 26 mm to 24 mm diameter a drop of 29.60% in cutting force and 38.89 % in radial force is recorded with 80 bar coolant pressure in relation with dry turning. While a drop of 22. 51 %% in cutting force and 33.33 % in radial force is recorded with 80 bar relative to wet machining. Similarly when compared to to 50 bar coolant pressure a drop of 13.29 % in cutting force and 2278 % in radial force is observed. The same trend of decrease in cutting and radial force components is observed for second cut from 24 mm to 22 is observed. For second cut a decrease of 25.56 % in cutting force and 29.22 % in radial force is recorded at 80 bar relative to dry turning. Whilst 25.81 % drop in cutting force and 33.64 % drop in radial force is recorded as compared to wet machining for machining at 80 bar. With 80 bar coolant pressure, results in decrease of 19.09 % in cutting force and 29.34 % in radial force as compared to 50 bar coolant pressure. Similar trends are also visible for 50 bar coolant pressure when it is compared with dry and wet machining.

This trend is mainly observed due to a fact that high pressure applied in this investigation at a point where chip originates. This results in two main benefits. First benefit is high pressure coolant improves curling and breaking of chips. Because of high velocities of high pressure coolant there is an impact of jet on chips due to chips get broken into small pieces or sometimes get curled. This action reduces frictional forces at cutting zone by reducing length of contact of chip with tool. To calculate force exerted by high pressure coolant the velocities of coolant are used which are calculated on basis of flow rates at 50 bar and 80 bar and cross sectional area of nozzle. Nozzle used in this investigation is of 1 mm and flow rate at 50 bar is 4 lpm and at 80 bar is 80- lpm.

From this velocities can be calculating as flow rate of coolant divided by cross sectional area of nozzle. These comes as 84.84 m/sec for 50 bar and 127.38 m/sec at 80 bar. So because of these high velocity impacts of jet the curling and braking of chips is more as compared to conventional wet machining and dry machining.

The second benefit of high pressure coolant in this investigation is, due the position of nozzle the coolant penetrates inside the cutting zone and also coolant is continuously supplied with same flow rate during the whole machining time since nozzle is fixed to turret it moves with turret during turning. So this improves lubricating conditions in cutting zone and reduces friction which is missing in dry turning and conventional wet turning.

Feed force does show much decrease for high pressure as compared to dry and wet machining. This may be because coolant is applied at high pressure in direction of feed which may result in additional forces in feed direction when machining with high pressure.

4 Conclusion

Machining Perfomamance analyais based on tool wear , surface roughness , quality of machned surface and cutting forces during Turning of Inconel 718 under Different Coolant Environment is preseneted in this study. Dry turning , Wet turning, Turning at coolant pressures of 50 bar and 80 bar are the machining environment studied during the investigation. This invetsigation concludes very imporatnt aspects for machining of Inconel 718 with high pressure coolant. Following are some concluding renmarks during the investigation with respect to conditions and parameters used for the study.

- Machining with High pressure coolant is very effective way to improve performance of machining because of better conditions in cutting zone as coolant gets forced inside the zone and provide lubricating effect.
- It is observed that at high pressures of 50 bar and 80 bar cutting tool can turn almost double length as that of dry turning and wet turning with very good surface finish and reduced cutting forces.
- An improvement of 18.77 % in surface roughness is observed while machining with 80 bar relative to wet machining. Similarly an improvement of 4.18 % and 4.32 % in surface roughness is observed with 80 bar in relation to dry and 50 bar coolant pressure machining respectively.
- SEM images of machined surface confirm that machining at high pressure i.e. at 80 bar and 50 bar pressure surface texture is very good with very few flaws. Only some traces of secondary carbide particles are observed at these high pressure coolant conditions. But with dry turning and wet machining many flaws are observed.
- Significant reduction in cutting force and radial is observed due to high velocity impact of high pressure coolant in cutting zone on chips which is not possible in dry turning and wet machining.

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