INVESTIGATIONS ON FINISH TURNING OF AISI 4340 STEEL IN DIFFERENT CUTTING ENVIRONMENTS BY CBN INSERT

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Abstract :
This paper presents the effects of minimal quantity lubrication (MQL) on the turning performance of AISI 4340 steel as compared to dry and wet machining in terms of surface roughness, cutting forces and tool wear. Twenty-seven experimental runs were performed based on an orthogonal array of Taguchi method. The effect of cutting speed, feed and cutting environment on tool wear, surface roughness and cutting force of the CBN insert was analysed using analysis of variance (ANOVA) technique and its optimum condition was derived. The R_a values for dry and wet environment were 1.2 µm and 1.1 µm respectively, whereas, in MQL condition it was 0.9 µm. This technique can serve as an environment friendly alternative solution to the conventional dry and wet turning.
Keywords: AISI 4340 steel, cutting forces, surface roughness, tool wear, minimal quantity lubrication (MQL).

1. Introduction

In recent times, modern machining industries are trying to achieve high quality, dimensional accuracy, surface finish, high production rate and cost saving along with reduced environmental impact.

Turning requires large quantities of coolants and lubricants that is why the total cost of production increases considerably. Conventional cutting fluid fails to penetrate the chip-tool interface and hence it cannot remove heat effectively. High pressure jet of soluble oil when applied at the chip-tool interface leads to reduced cutting temperature and improves tool life up to some extent. However, inappropriate handling of cutting fluid may damage soil and water resources. Therefore, handling and disposal of cutting fluids must obey rigid rate of environmental protection.

The increased use of cutting fluids increases the total machining cost considering high cost associated with the use of cutting fluid. Hence, some methods like dry machining, machining with MQL and cryogenic machining can serve as alternatives.

A study of performance in machining of different materials with dry, wet, MQL and cryogenic cooling is available in open literature. The review of the literature suggests that MQL application provides several benefits in machining. The specific function of the cutting fluid in the machining process is to provide lubrication and cooling to minimize the heat produced between the surface of the workpiece and tool. MQL is an alternative to reduce the friction and hence prevent the adherence of the material. The consumption of the cutting fluid in MQL is usually less than 300 ml/hr.

The advantages of MQL are:

- Less polluted
- Labour costs are reduced while disposal.

The cost associated mainly in handling the cutting fluid, recycling and disposal is leading to alternatives such as new tool material and coating, which allows dry machining and application of small quantities of fluid as a mist spray. Machado and Wall bank (1997) have studied the application of cutting fluid as a spray mist at rates of 200-300 ml/hr while turning the medium carbon steel. They found that at low cutting speeds and high feed rates; the cutting and feed forces were lower.

Sharma et al. (2009) noticed that MQL has resulted in reduction in friction and heat at cutting zone. Hence, it improved productivity of the process. M.M.A. Khan et al. (2009) studied the effect of MQL on turning AISI 9310 alloy steel using vegetable oil based cutting fluid. Results show that MQL provides environment friendly and improved machinability characteristics. Chiffre (2009) investigated the capability of the reaming process using MQL and found that the hole dimensions and surface finish were improved. Kress (1997) noticed that the machining cost is one of the important aspects to be considered. Dhar et al. (2007) reported that the machining performance of AISI 1060 in MQL environment of vegetable oil is better than that of dry machining. An experimental investigation shows that MQL reduces the cutting forces by 5-15%. The surface finish affected the performance and service life of the machined/ground components. MQL environment gives better surface finish than the dry and flood cutting irrespective of cutting velocity, feed rate and length of cut. An investigation by Kumar et al. (2006) gives an idea about the comparative performance of different coated tools in conventional dry turning and wet turning process with the MQL method by varying speed and feed; keeping the depth of cut as constant. Overall performance of the cutting tool during the MQL application found superior over the dry turning and conventional wet turning based on the parameters such as cutting force, temperature and surface finish. By carefully choosing these parameters, it is possible to produce high quality components with the MQL.

The form of chip produced is one of the major parameters influencing the productivity in the metal cutting industry, which is tightly prevalent during dry cutting. As water vapour is prone to reduce the main cutting force and improve the friction status of the rake face and chip, it can be an advantage in forming acceptable chips Lin et al. (2007) reported that in hard turning of AISI 4340 at low cutting speed the chip is a continuous type.

2. Experimental work

In the present work, an attempt was made to study the effect of MQL turning of steel AISI 4340 by CBN insert on cutting forces, surface finish and its comparison with dry and wet turning. In addition to the cutting environments, the process parameters used were cutting speed and feed rate. The cutting environmental conditions were changed in three levels like dry, wet and MQL. The response variables selected to achieve better machining and tool performance were surface roughness, cutting force components and tool wear. The experiments were conducted using the standard L_{27} Taguchi orthogonal array. The experimental conditions are given in Table 1.

Table 1 Input factor and other experimental details

Factors	Machining parameter	Unit	Level		
			1	2	3
Variables	Cutting Speed, *V*	m/min	180	200	220
	Feed Rate, f	mm/rev	0.04	0.05	0.06
	Depth of Cut, *d*	mm	0.5	0.5	0.5
	Environmental condition		Dry	Wet	MQL
Fixed	Tool geometry (clearance angle= 0° , 80° rhombus shape, back rake angle = -6°, approach angle=95°, side cutting edge angle=5°)				
	Tool material (CBN inserts) which contains 50% CBN and TiC binder. The insert grade- MT KB 5625				
	Tool holder -PCLN L 2525 M12.				
	Material- AISI 4340 with diameter 50 mm and 150 mm working length. Material is hardened up to 179 BHN.				
	Machine tool used- A high speed precision CNC Lathe, Jobber XL Make, Model NH 22, 7.5 HP				

2.1. Cutting fluid and its application

Since the quantity of cutting fluid used in this method is very low (5 ml/min), specially formulated cutting fluid is used. The base oil (commercially available mineral oil) is properly formulated by adding additives such as surfactant, evaporator, emulsifier, stabilizer etc. Fig.1 shows the experimental setup used and supply the MQL at 5 ml/min. The input of the lubricator is connected a compressor supplying air at pressure of 6 bar. The mist air coming out from the lubricator is used as cutting fluid. The lubricator knob is adjusted such that the oil flow rate is 5 ml/min.

Fig.1. Experimental set up showing minimal cutting fluid delivery unit

2.2. Experimental procedure

A cylindrical workpiece of steel AISI 4340 having diameter 50 mm and length 150 mm was mounted on rigid CNC lathe machine with tail stock support. A CBN insert with MT KB 5625 grade was clamped on tool holder PCLN L 2525 M12, which was mounted on the top plate of the Kistler dynamometer. Forces measured online with Kistler dynamometer were recorded using dynoware software. After performing a series of experiments, the roughness value and its corresponding tool wear were measured by Mitutoyo surface tester and Nikon microscope respectively.

3. Results and discussion

The analysis of experimental data was performed in order to determine the effect of cutting speed, feed rate, depth of cut and cutting environment on the magnitude of cutting forces, surface roughness and tool wear. Statistical analysis was performed. The results are presented using main effects and interaction plots.

4. Statistical analysis of cutting force (F_z)

The main effects plots for cutting force and the table of analysis of variance (ANOVA) is shown in Fig. 2 and Table 2 respectively.

Table 2 ANOVA for cutting force F_z (N)

Source of variance	Degrees of Freedom (DOF)	Sum of Squares (SOS)	Adjusted (SS)	Adjusted(MS)	F Ratio $\alpha = 5\%$	P Value
Cutting Environment(E_v)	2	82551.2	82551.2	41275.6	668.48	0.000
Cutting Speed m/min (V_c)	2	11689.6	11689.6	5844.8	94.66	0.000
Feed mm/rev (f)	2	1417.5	1417.5	708.8	11.48	0.004
Cutting Environment(E_v)* Cutting Speed (V_c)	4	233.2	233.2	58.3	0.94	0.486
Cutting Environment (E_v) *Feed (f)	4	227.9	227.9	57.0	0.92	0.496
Cutting Speed (V_c)*Feed (f)	4	104.6	104.6	26.1	0.42	0.788
Error	8	494.0	494.0	61.7		
Total	26	96718.0				
S = 7.85785 R-Sq = 99.49% R-Sq(adj) = 98.34%						

It is observed from ANOVA that the cutting environment has statistically significant effect on the cutting forces produced during turning of steel AISI 4340. This variable is statistically significant at more than 95%. Other input variables have shown less significance on the cutting forces.

4.1. Effect of cutting speed on cutting force (F_z)

The main effects plots (Fig.2) shows that, at a cutting speed of 180 m/min the cutting forces are near about 100 N, but at cutting speed of 200 m/min, the cutting forces increases up to 130 N. As cutting speed increases from 180 m/min to 200 m/min, the slight increase in cutting force to 130 N was observed. There were two possible reasons behind this. First one, at lower cutting speed the formation of Built-Up-Edge (BUE) results into an increase in cutting force. However, as the cutting speed increases, the tendency of formation of BUE decreases. Another reason is the decrease in contact area and a resultant drop in the shear strength in cutting zone as the cutting temperature increases with an increase in cutting speed. Fig. 3 shows that for speed from 200 m/min to 220 m/min the cutting force in MQL is very low compared to dry and wet environment.

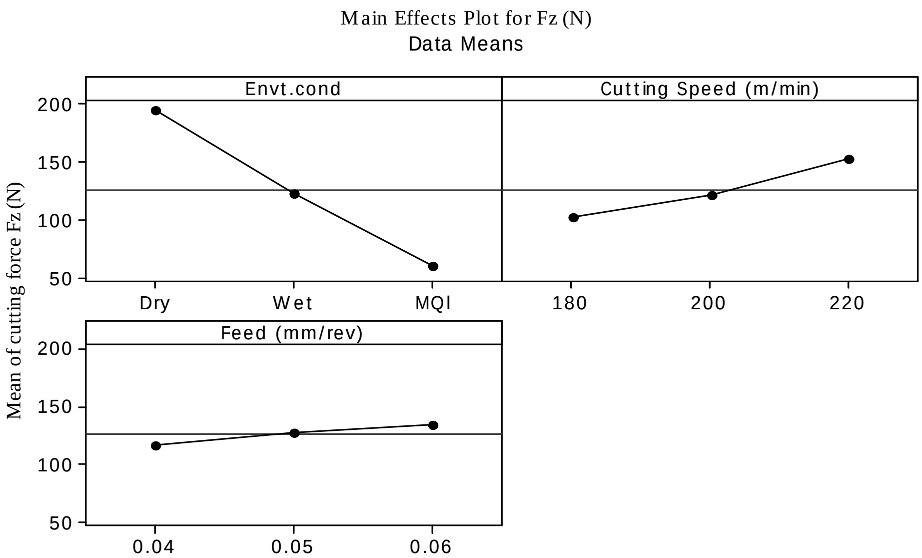

Fig. 2. Main effects plot for cutting force F_z (N)

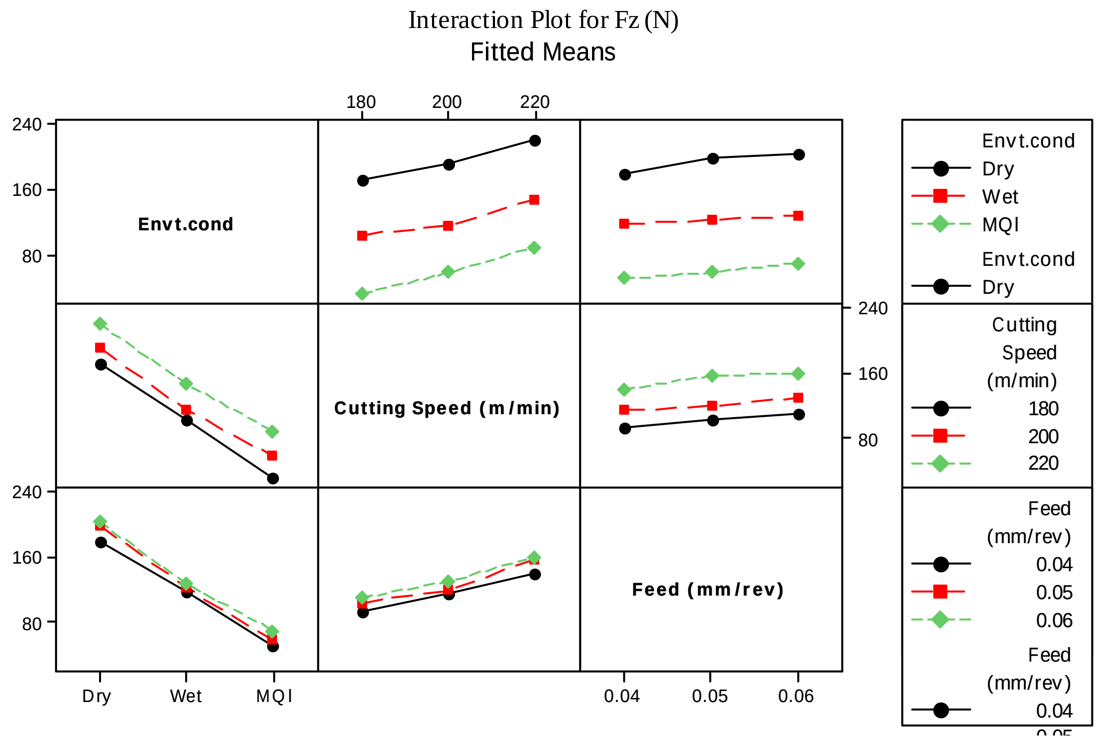

Fig. 3. Interaction plot for cutting force F_z (N)

4.2. Effect of feed on cutting force (F_z)

It was observed that the feed rate has less influence on the magnitude of cutting force (F_z).As the feed rate is 0.04 mm/rev, the cutting force is 180 N for dry condition. At the same time cutting force decrease for wet and MQL condition. Similarly, as feed increases, cutting force also increases. However, the requirement of cutting force for MQL is much lower as compared to dry and wet environment (Fig.3)

4.3. Effect of cutting environment on cutting force (F_z)

Fig. 2 shows that the cutting forces produced in MQL are lower than that of the dry and wet turning. In the case of dry turning, the cutting force is 195 N and in wet turning, the force reduces to 125 N, whereas in MQL the cutting force is 55 N. In MQL, the cutting fluid is supplied at high pressure (6 bar) and high velocity, due to which fluid particles can reach up to tool chip interface in the form of small drops. During MQL, the cutting fluid is fragmented into tiny globules. Its size is inversely proportional to the pressure of cutting fluid. The velocity varies as a function of the square root of pressure. This high velocity results into the better penetration of cutting fluid to the underside of the chip. This creates its passage to reduce the friction between tool and chip. The reduction in friction thus reduces the cutting force. Such condition is not prevailed in wet turning because there is no such fragmentation phenomenon since velocity and pressure in wet turning is less than MQL.

During wet turning, the heat is extracted only by convective heat transfer, but during MQL, cooling occurs by convective as well as evaporative heat transfer. During MQL environment, high velocity droplets can puncture the cover of vapour formed and reach up to hot tool interface facilitating evaporative heat transfer. Thus, the total heat transfer is sum of convective and evaporative heat transfer. This heat transfer leads to lowering the cutting temperature, which is not possible in case of wet and dry turning.

5. Statistical analysis of feed force (F_x)

The feed force acts axially i.e. along the axis of rotation. It is observed from the ANOVA (Table 3) that the cutting speed and cutting environments are statistically significant parameters at more than *95%* CI.

Table 3 ANOVA for feed force F_x (N)

Source of variance	Degrees of Freedom (DOF)	Sum of Squares (SOS)	Adjusted (SS)	Adjusted(MS)	F Ratio α = 5%	P Value
Cutting Environment(E_v)	2	39271.6	39271.6	19635.8	62.93	0.000
Cutting Speed m/min (V_c)	2	17824.9	17824.9	8912.5	28.56	0.000
Feed mm/rev (f)	2	3951.9	3951.9	1975.9	6.33	0.022
Cutting Environment(E_v)* Cutting Speed (V_c)	4	14799.0	14799.0	3699.8	11.86	0.002
Cutting Environment (E_v) *Feed (f)	4	4443.7	4443.7	1110.9	3.56	0.060
Cutting Speed (V_c)*Feed (f)	4	1238.9	1238.9	309.7	0.99	0.464
Error	8	2496.3	2496.3	312.0		
Total	26	84026.3				
S = 17.6645 R-Sq = 97.03% R-Sq(adj) = 90.34%						

5.1. Effect of cutting speed on feed force (F_X)

It is observed from main effects plots (Fig.4) that, as the cutting speed increases from 180 m/min to 200 m/min, feed force increases from about 42 N to 68 N. The reason is at lower cutting speed, the formation of BUE resulted into an increase in feed force. However, as the cutting speed increases further; the tendency of formation of BUE decreases. Being a ductile and gummy nature of work material, a tendency to form BUE at lower cutting speed is more. However, as the cutting speed increases BUE formation ceases so that feed force decreases with an increase in cutting speed. Fig.5 shows the variation in feed force in different cutting environments for the same speed.

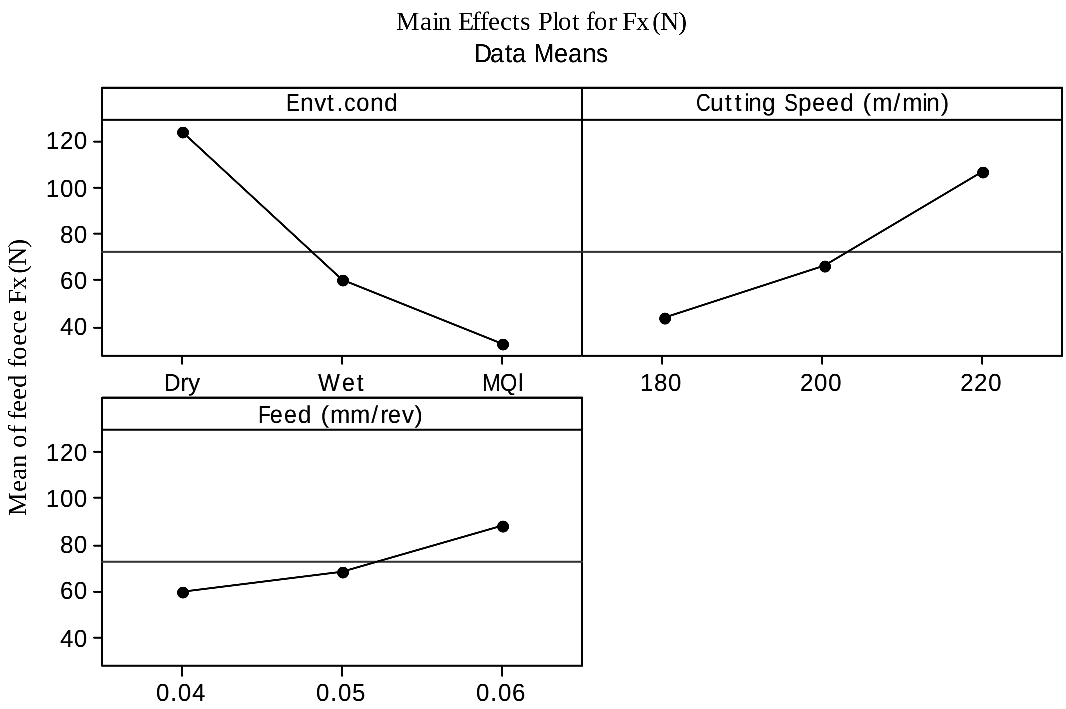

Fig. 4. Main effects plot for feed force F_x (N)

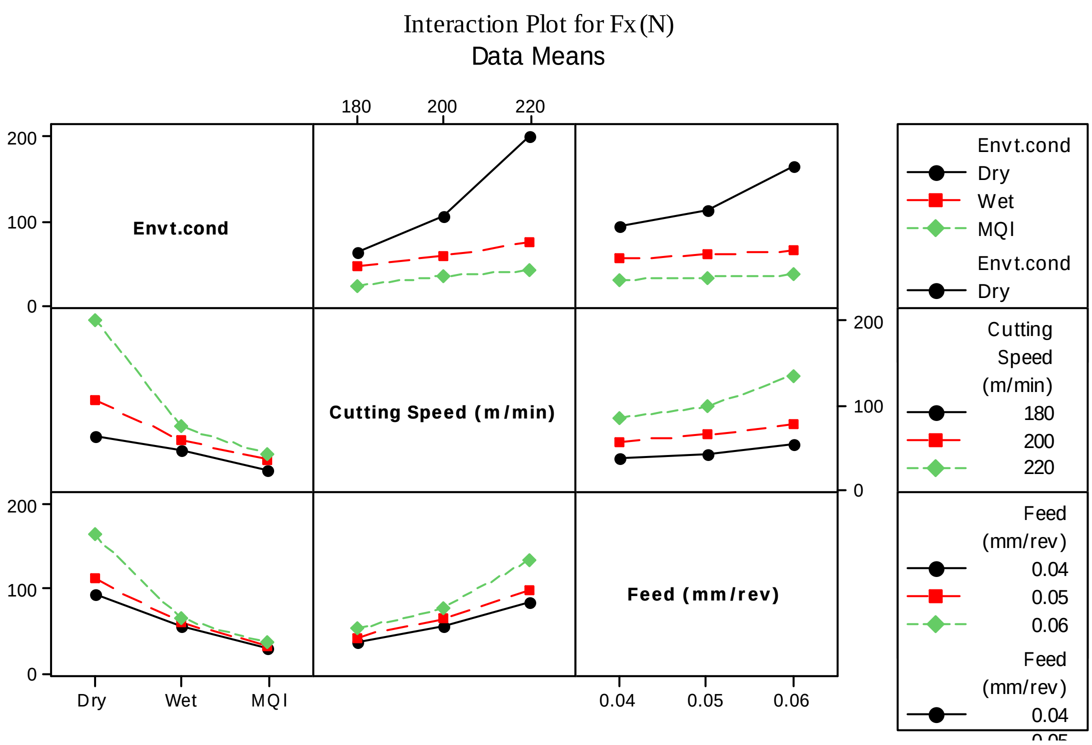

Fig. 5. Interaction plots for feed force F_x (N)

5.2. Effect of feed rate on feed force (F_x)

The main effects plots (Fig. 4) of feed force shows that as the feed rate increases from 0.04 mm/rev to 0.05 mm/rev, the feed force increases from 60 N to 78 N. Nevertheless, as the feed rate increases from 0.05 mm/rev to 0.06 mm/rev the increase in feed force is further more. At the lower feed rate, resistance to the tool in the feed direction is less. Also, as the feed increases higher resistance is exerted the tool propagation .The feed force for a feed rate of 0.06 mm/rev is more in dry than in MQL environment (Fig.5).

5.3. Effect of cutting environment on feed force (F_x)

Fig.5 shows comparison of feed force produced in MQL with that of dry and wet turning of steel AISI 4340 machined with CBN insert. It is noticeable that the feed force produced in MQL is lower than the feed force produced in dry and wet turning. In the case of dry turning, the feed force is 120 N and in wet turning, the force reduces below 120 N whereas in MQL it is further lower. In MQL, the cutting fluid is supplied at high pressure (6 bar) and high velocity as a result the fluid particles can reach up to tool chip interface in the form of small drops. The velocity varies as a function of the square root of pressure. This high velocity results into better penetration of cutting fluid at underside of the chip .This creates its passage to reduce the friction between tool and chip. The reduction in friction thus reduces the feed force. Such condition is not prevailed in wet turning as there is no such fragmentation phenomenon since velocity and pressure in wet turning is less than that in MQL.

6. Statistical analysis of radial force (F_y)

The main effects plots for radial force and the table of analysis of variance (ANOVA) are shown in Fig.6 and Table 4 respectively. A radial force acts perpendicular to both cutting force and feed force. It is observed from the ANOVA (Table 4) that the cutting speed, feed rate are statistically significant at 95%.

Table 4 ANOVA for radial force F_y (N)

Source of variance	Degrees of Freedom (DOF)	Sum of Squares (SOS)	Adjusted (SS)	Adjusted(MS)	F Ratio $\alpha = 5\%$	P Value
Cutting Environment(E_v)	2	20389.8	20389.8	10194.9	242.10	0.000
Cutting Speed m/min (V_c)	2	3578.4	3578.4	1789.2	42.49	0.000
Feed mm/rev (f)	2	534.4	534.4	267.2	6.35	0.022
Cutting Environment(E_v)* Cutting Speed (V_c)	4	552.7	552.7	138.2	3.28	0.072
Cutting Environment (E_v) *Feed (f)	4	91.8	91.8	23.0	0.55	0.708
Cutting Speed (V_c)*Feed (f)	4	148.5	148.5	37.1	0.88	0.516
Error	8	336.9	336.9	42.1		
Total	26	25632.6				
S = 6.48926 R-Sq = 98.69% R-Sq(adj) = 95.73%						

6.1. Effect of cutting speed on radial force (F_y)

As cutting speed increases from 180 m/min to 200 m/min and 220 m/min, there is increase in radial force from 60 N to 68 N and 85 N respectively. The variation in radial force in different cutting environment for same speed is shown in Fig.6

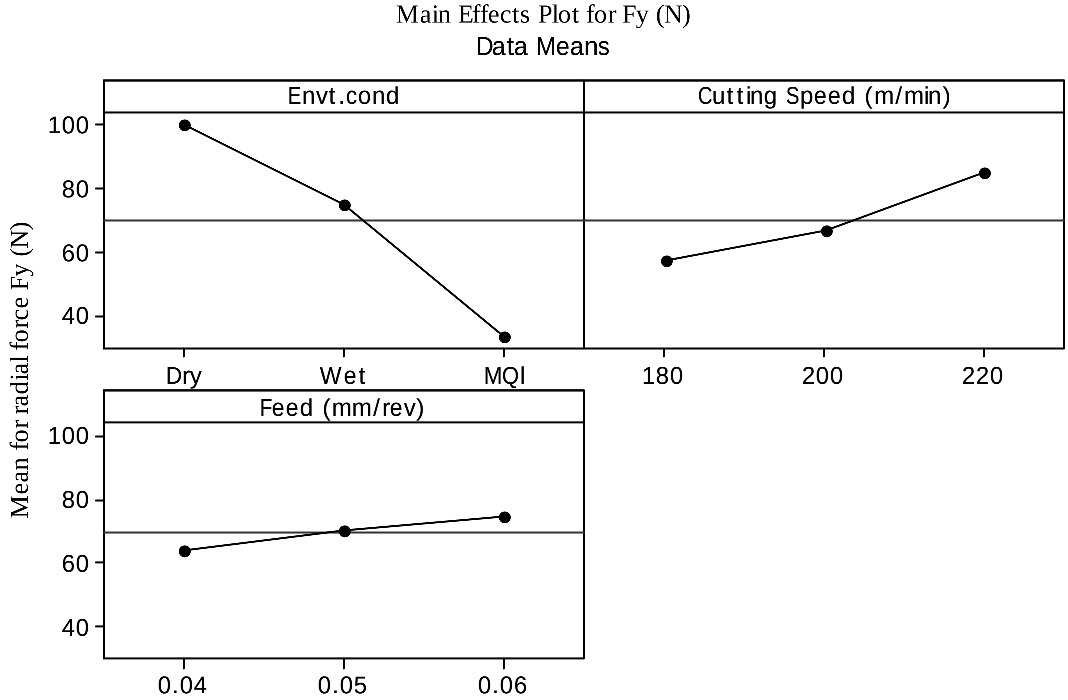

Fig. 6. Main effect plots for radial force F_y (N)

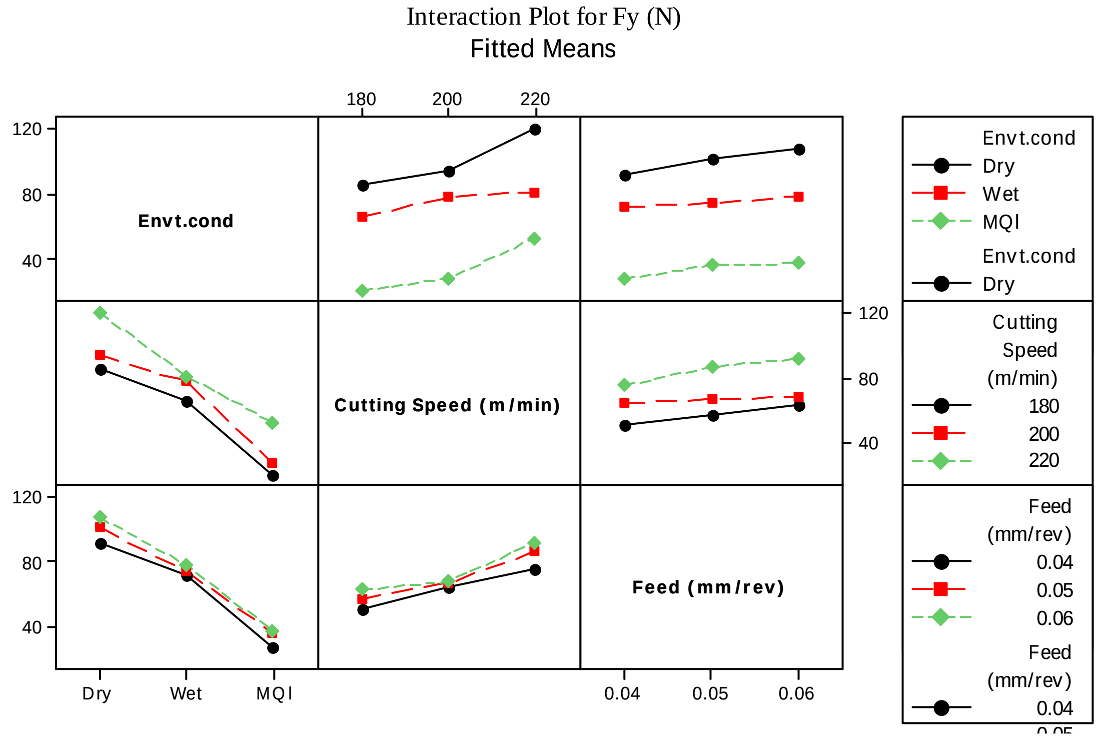

Fig. 7. Interaction plots for radial force F_y (N)

6.2. Effect of feed rate on radial force (F_y)

The effect of feed rate on radial force shows that when feed rate increases from 0.04 mm/rev to 0.05 mm/rev, there is increment in radial force from 60 N to 70 N. However, for further increment in feed rate up to 0.06 mm/rev, the rate of increase of radial force becomes higher and it increases up to 80 N (Fig.6). For dry condition 110 N is a higher radial force at 0.06 mm/rev feed rate. At the same time, the radial force is much lesser for MQL, which is about 40 N (Fig.7).

6.3. Effect of cutting environment on radial force (F_y)

Fig.6 shows comparison of radial force component produced in MQL with dry and wet turning of steel AISI 4340 machined with CBN insert. It is observed that the radial force produced in MQL is lower than that in dry and wet turning. In the case of dry turning, the radial force magnitude is 100 N and in wet turning, the force reduces to 70 N whereas in MQL the cutting force is 35 N. During MQL, the cutting fluid is fragmented into tiny globules, which is reached up to tool-chip interface.

7. Statistical analysis of surface roughness value (R_a)

The surface roughness value (R_a) measures the degree of surface finish. Lower the value of R_a, higher is the surface finish. It is observed from the ANOVA (Table 5) that the cutting speed, feed rate and cutting environment are statistically significant.

Table 5 ANOVA for surface roughness value R_a (μm)

Source of variance	Degrees of Freedom (DOF)	Sum of Squares (SOS)	Adjusted (SS)	Adjusted(MS)	F Ratio α = 5%	P Value
Cutting Environment(E_v)	2	0.27701	0.27701	0.13850	33.32	0.000
Cutting Speed m/min (V_c)	2	2.02005	2.02005	1.01003	243.00	0.000
Feed mm/rev (f)	2	0.21676	0.21676	0.10838	26.08	0.000
Cutting Environment(E_v)* Cutting Speed (V_c)	4	0.05479	0.05479	0.01370	3.30	0.071
Cutting Environment (E_v) *Feed (f)	4	0.03428	0.03428	0.00857	2.06	0.178
Cutting Speed (V_c)*Feed (f)	4	0.01930	0.01930	0.00483	1.16	0.396
Error	8	0.03325	0.03325	0.00416		
Total	26	2.65545				
S = 0.0644708 R-Sq = 98.75% R-Sq(adj) = 95.93%						

7.1. Effect of cutting speed on surface roughness (R_a)

It is observed from main effects plots Fig.8 that, as cutting speed increases from 180 m/min to 200 m/min, surface roughness value (R_a) decreases from 1.4 μm to 0.7 μm. The reason being that, at higher cutting speed there is no formation of BUE, which results into good surface finish.

Tendency to form BUE at lower cutting speed is more but as the cutting speed increases BUE formation ceases resulting into a reduction in friction force, which leads to improvement in surface finish. The roughness value in MQL environment is much less than dry environment. In dry environment the roughness value is about 1.2 μm and that in MQL environment is about 1 μm.

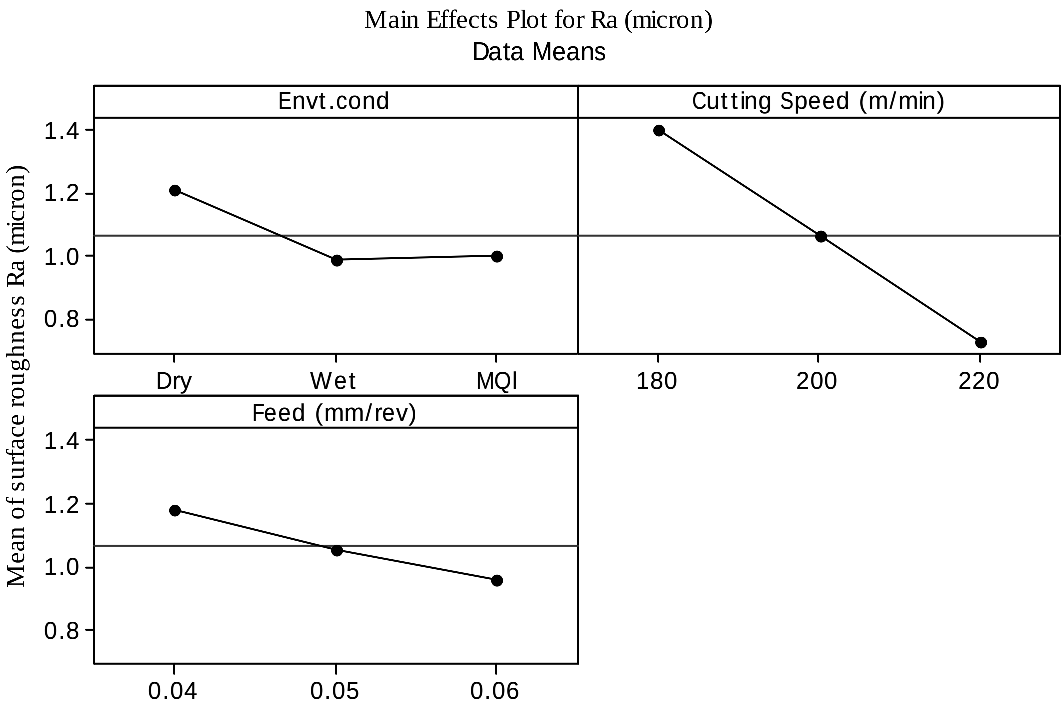

Fig.8 Main effect plots for surface roughness R_a (µm)

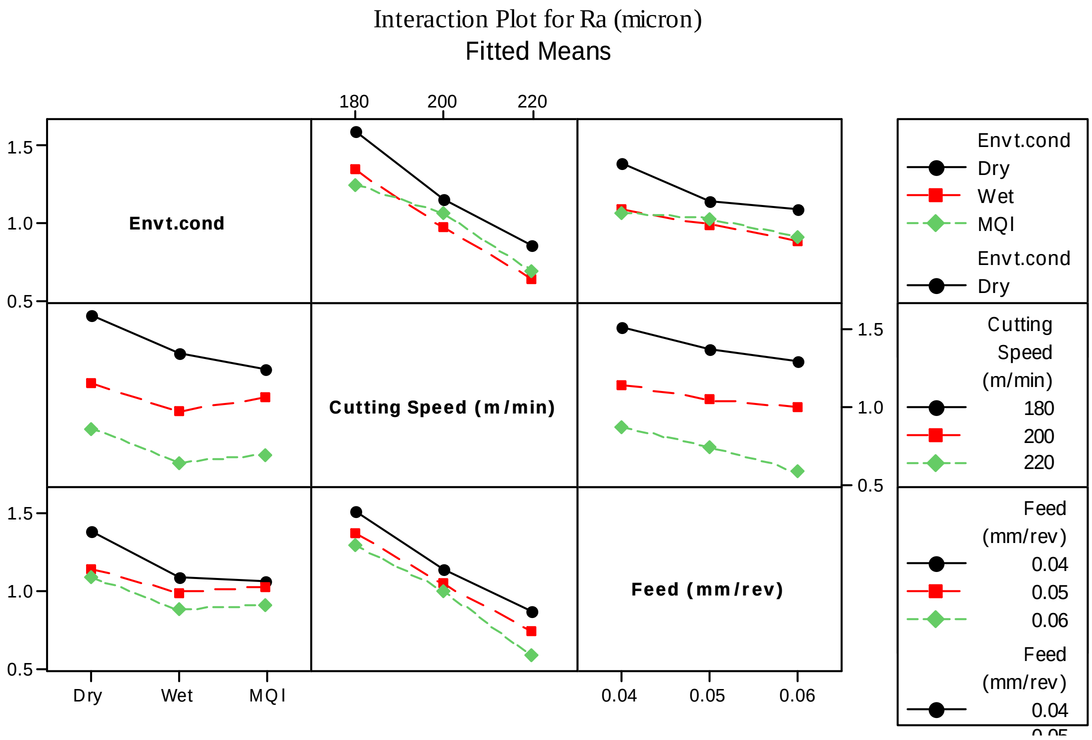

Fig. 9. Interaction plots for surface roughness R_a (µm)

7.2. Effect of feed rate on surface roughness (R_a)

From Fig.8, it is observed that, the feed rate has abnormal influence on the surface roughness value (R_a). As the feed rate increases from 0.04 mm/rev to 0.05 mm/rev, the surface roughness decreases from 1.2 µm to 1 µm. Further increase in feed rate from 0.05 mm/rev to 0.06 mm/rev, the surface roughness value decreases from 1.00

µm to 0.9 µm. Fig.9 shows the variation in roughness value in different cutting environment for same feed rate. In MQL environment, roughness value is very low than that in dry and wet environment.

7.3. Effect of cutting environment on surface roughness (R_a)

Fig. 9 shows comparison of surface finish in MQL with dry and wet turning of alloy steel AISI 4340 by CBN insert. It is observed that, the surface finish in MQL is much better than that of in dry and wet turning**.** The R_a value for dry turning is 1.2 µm and for wet turning, it is about 1.1 µm whereas in MQL turning it is 0.9 µm. The reduction in cutting force results in reduction in friction. Thus, reduction in friction i.e. cutting force results in better surface finish.

8. Statistical analysis of tool wear

Tool wear can be calculated in various ways. The gradual and progressive wear takes place in the regions of the face and flank of the cutting tool respectively. Wear on the flank of cutting tool is caused by friction between the newly machined workpiece surface and the contact area of the flank. It is observed from the ANOVA (Table 6) that, the environmental condition and feed rate are statistically significant.

Table 6 ANOVA for tool wear (mm)

Source of variance	Degrees of Freedom (DOF)	Sum of Squares (SOS)	Adjusted (SS)	Adjusted(MS)	F Ratio $\alpha = 5\%$	P Value
Cutting Environment(Ev)	2	0.1261336	0.1261336	0.0630668	1203.51	0.003
Cutting Speed m/min (V_c)	2	0.0217764	0.0217764	0.0108882	207.78	0.015
Feed mm/rev (f)	2	0.0025261	0.0025261	0.0012630	24.10	0.001
Cutting Environment(E_v)* Cutting Speed (V_c)	4	0.0028103	0.0028103	0.0007026	13.41	0.001
Cutting Environment (E_v) *Feed (f)	4	0.0004782	0.0004782	0.0001196	2.28	0.149
Cutting Speed (V_c)*Feed (f)	4	0.0001847	0.0001847	0.0000462	0.88	0.516
Error	8	0.0004192	0.0004192	0.0000524		
Total	26	0.1543285				
S = 0.00723896 R-Sq = 99.73% R-Sq(adj) = 99.12%						

8.1. Effects of cutting speed on tool wear

It is observed from main effects plots (Fig. 10) that, as cutting speed increases from 180 m/min to 200 m/min, tool wear value increases from 0.10 mm to 0.17 mm. From Fig.11, it is found that, in case of dry environment the rate of tool wear is comparatively high from 0.02 to 0.10. During MQL the tool wear difference is low; about 0.2 mm to 0.24 mm.

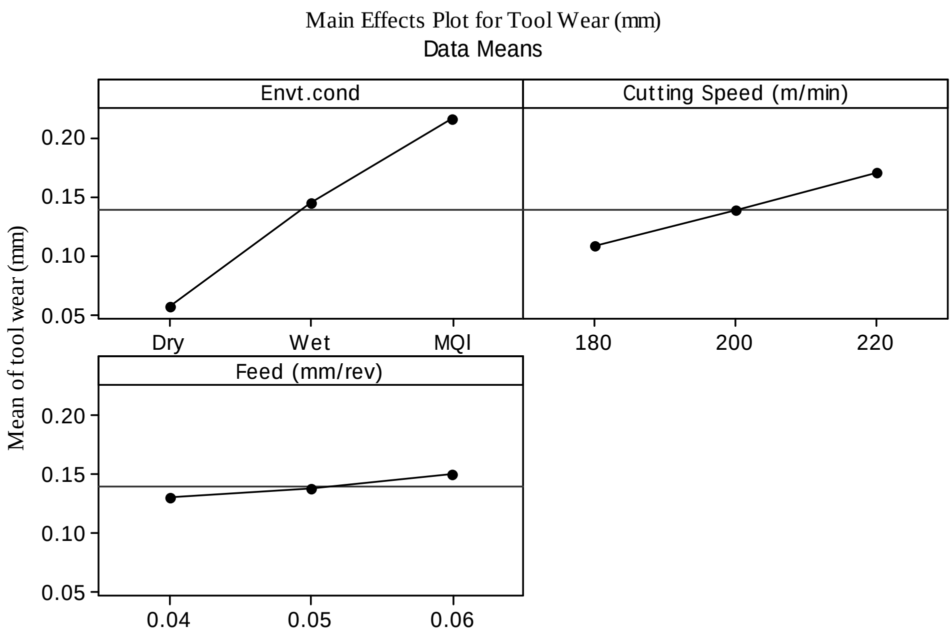

Fig. 10. Main effect plots for tool wear (mm)

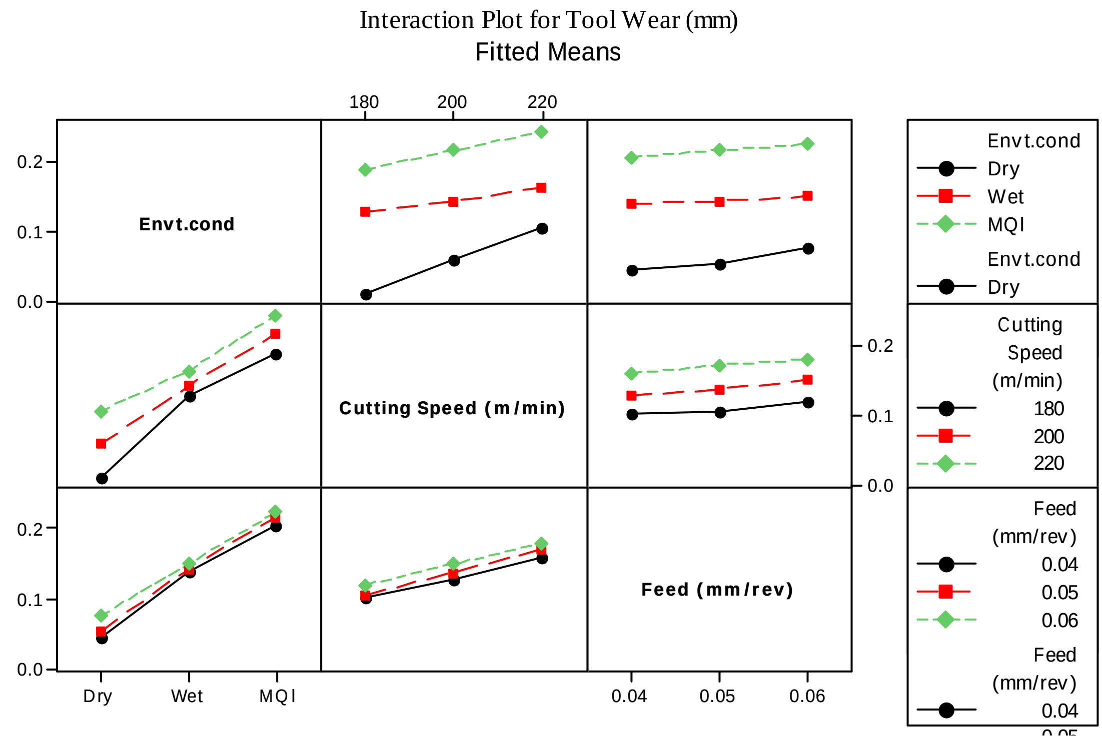

Fig. 11. Interaction plots for tool wear (mm)

8.2. Effects of feed rate on tool wear

It is observed from Fig.11 that, as feed rate increases from 0.04 mm/rev to 0.05 mm/rev, tool wears value increases from 0.14 mm to 0.15 mm. From Fig.11, it is found that, in case of dry environment the rate of tool wear is comparatively high from 0.04 to 0.08. During MQL the tool wear difference is low; about 0.2 mm to 0.24 mm. The pie charts show the percentage wear at different cutting environment, cutting speed and feed. (Fig.12-14)

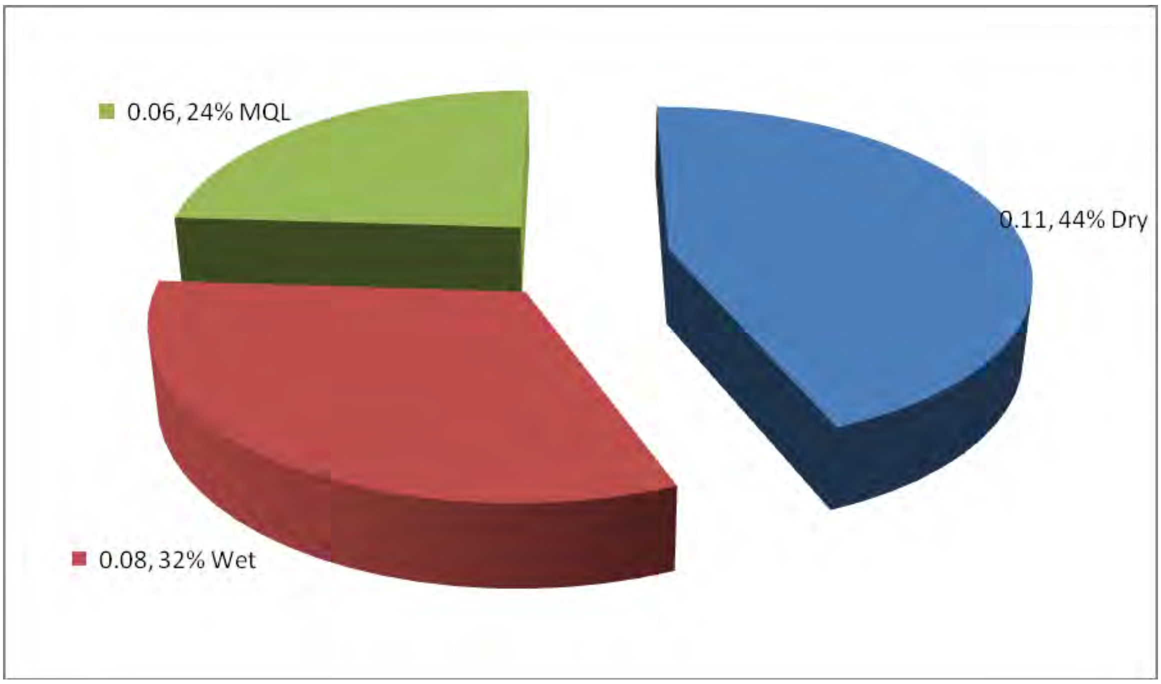

Fig. 12. Tool wear in various environmental conditions

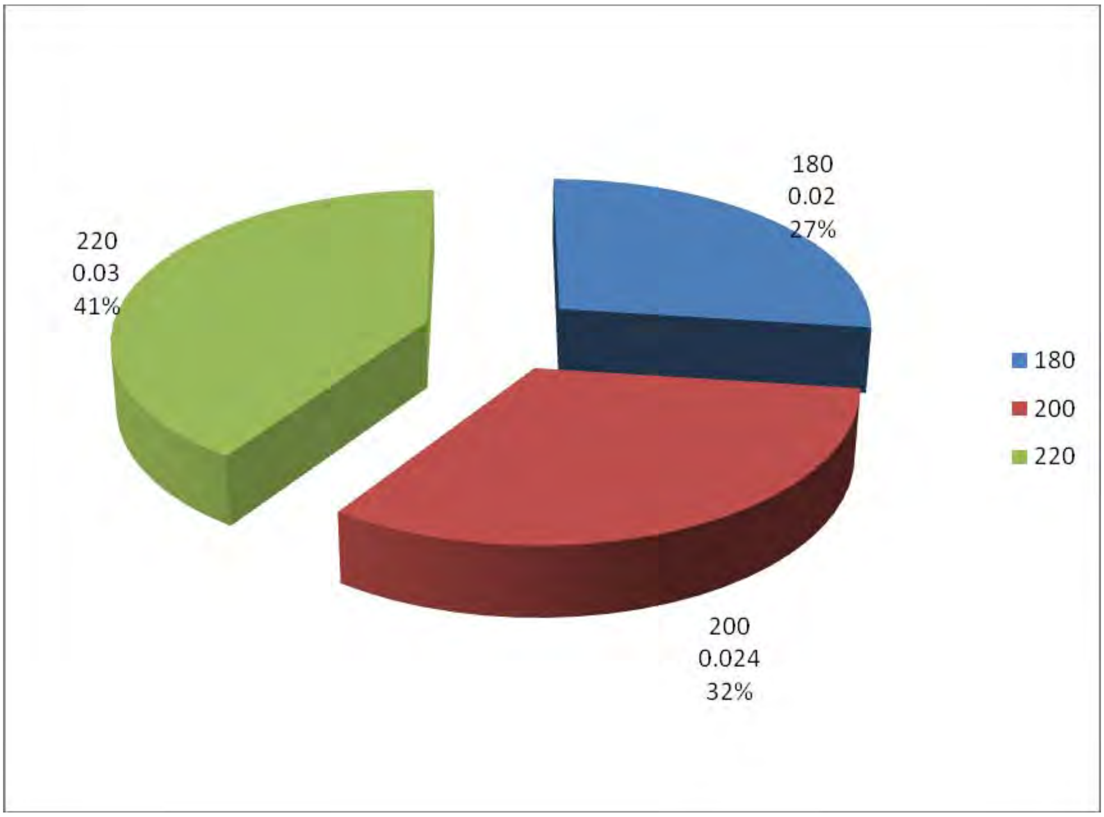

Fig. 13. Tool wear in various cutting speeds (m/min)

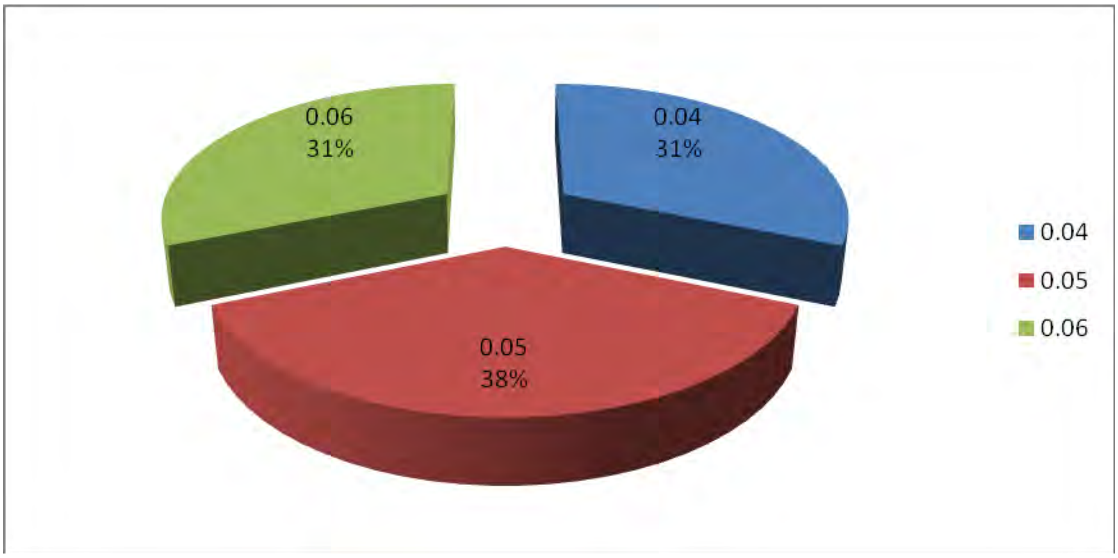

Fig. 14. Tool wear in various feeds (mm/rev)

9. Performance of tool in turning operation

Fig. 15 shows the growth of flank wear with machining time for CBN tool. During the turning operation it is found that, there is rapid initial wear because of sharp cutting edge of the tool and because of friction between the newly machined workpiece surfaces. The tool wear is determined by toolmaker's microscope. During initial condition tool wear increases rapidly as the sharp cutting edge is quickly broken down. After 30 minutes, wear progresses at uniform rate. Machining time depends on spindle speed, feed and machining length. As cutting speed and feed increases, time required to machine is less. Therefore, from Fig.15 it is observed that the time required to machine becoming lower after 50 minutes. Fig.16 indicates the initial and final condition of tool wear.

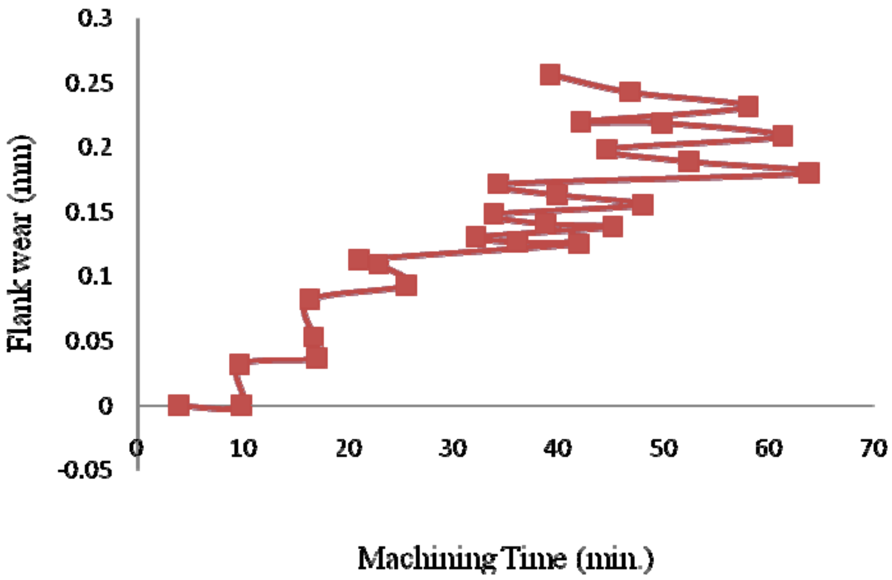

Fig. 15. Growth of flank wear during turning

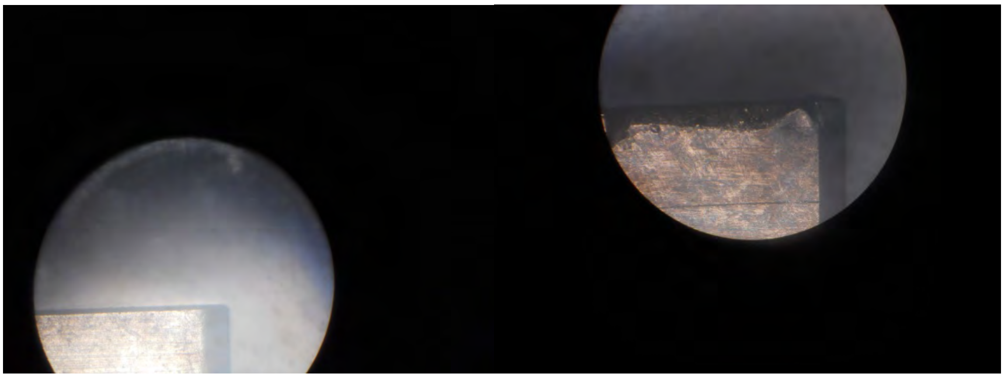

Fig. 16. Initial and final condition of tool wear

10. Testing of tool wear using scanning electron microscope

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals. It contains information about the sample's surface topography, composition and other properties such as electrical conductivity.

A SEM analysis is performed in order to investigate how the tool wear takes place in different environmental conditions. Fig. 17 shows the nature of the tool wear. The SEM views of the worn out insert after being used for about 65 minutes of machining under dry, wet and MQL conditions are shown in Fig.17. Under all the environments, abrasive scratch marks appeared in the flank face. There are also some indications of adhesive wear in the insert. Some plastic deformation and micro chipping were found. Severe groove wear and notch wear at the flank surfaces were found in insert. The notch wear on main cutting edge develops mainly because of oxidation and chemical wear. Effective temperature control by MQL almost reduced the growth of notch and groove wear on the main cutting edge.

Fig. 17. SEM view of worn out insert (flank surface) after machining

11. Conclusions

From the experimental investigations based on Taguchi's method and the analysis of the results, the following conclusions are drawn.

- It is observed from the ANOVA that, the cutting speed and cutting environment both have statistically significant effect on the cutting forces. In the MQL environment, the cutting forces were found lesser as compared to dry and wet environment.
- The cutting environment is only statistically significant at more than *95%* confidence interval effect on the surface roughness value.
- It was found that, the R_a value for dry and wet turning is 1.2 µm and 1.1 µm respectively. In the case of turning in MQL condition, the R_a value is 0.9 µm.
- This technique can form a viable alternative to conventional wet turning.

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