Enhancement of surface finish and tool wear assessment through minimum quantity lubrication machining on AISI D2 steel

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Abstract

In machining, the quality of the product is mostly depending upon its surface finish. So many methods are employed to improve the surface finish of the workpiece in machining, even though some factors have played a vital role, such as tool tip temperature, friction, depth of cut (doc) act as a barrier to the surface finish in the machined part. In the current scenario, the minimum fluid application is employed in machining to reduce tool tip temperature (Temp) and improve the surface roughness (SR). But in Minimum Quantity Lubrication (MQL) machining, the control of cutting fluid rate is the most important one to create the atomization process nearer to cutting zone during the machining. The present work mainly focuses on the application of MQL by using coconut oil in the turning of AISI D2 steel with Cubic Boron Nitride (CBN) as a cutting tool insert. More attention was given to the tool wear investigation in cutting tool during different machining environment conditions. Flank wear, nose wear and crater wear were identified and chip morphology study has also taken part in this investigation. A combined approach of Response Surface Methodology (RSM) with Simulated Annealing Algorithm (SAA) method gives predicted parameters to reduce tool tip temperature and surface roughness value in hardened steel. This paper presents the comparison results of surface roughness, tool tip temperature of the machined work piece using dry machining and minimum quantity lubrication machining from the experimental method, simulated annealing and response surface methodology. The tool wear study was also studied by using scanning electron microscope (SEM). This concept can be recommended for industries to improve the surface finish due to less cutting force, reduce the temperature in cutting zone, tool wear and frictional force.

Keywords: *Surface roughness, tool wear, minimum quantity lubrication, tool tip temperature, response surface methodology, simulated annealing and chip morphology.*

1. Introduction

In machining of difficult to cut materials having hardness more than 63HRC, cutting fluids help to improve the surface finish and to decrease the tool tip temperature of the cutting zone between tool and work piece. In these current circumstances, all manufactures have taken steps to execute green manufacturing to provide better products. But utilization of more amount of cutting fluids in machining creates an unpleasant environment for operators. In order to provide Eco friendly machining, adopting minimum fluid application machining is the best way to reduce the hazard problems to operators.[1]Use AISI P20 and D2 steel implemented a technique of minimum fluid application with a different aerosol temperature difference between 50^0C to 250^0C. At last they concluded that the surface roughness value was gradually increased with increase in temperature at cooling conditions. Comparing both P2O and D2 steel nearly 50% reduction in surface roughness value in the flood machining process. Comparison between numerical modeling with experimental result shows that the droplet range between 6 microns to 16.3 microns (μm) gives more effective lubrication to reduce the force between the workpiece and grinding wheel [4]. [5] Uses three different types of abrasive particles combined with SAE-40 base oil. Chip thickness and surface roughness were taken as effective output parameters with different combinations of speed, feed, nose radius and concentration of lubricant. EN-31 steel was used as the work piece and the grey relational approach was implemented in his research. The optimal parameter of minimum surface roughness was achieved in by using 10% concentration of boric acid + SAE40 base oil. In this study [6] two different aluminium alloys were involved. MQL technique was applied to investigate surface roughness is four different flow rate conditions such as 0.25 ml/min, 0.45 ml/min, 0.90 ml/min, 3.25ml/min.The effect of cutting speed builds more impact on surface roughness of the machined part. Finally the research reported that Material type is less dominant factor. Cutting tool temperature [7] was measured by using the non-contact chromel–alumel thermocouples. Cold air jet, flood cooling, cold water mist jet methods was carried out. In their research the heat transfer coefficient increases along with the temperature increment. Cutting speed increases, which increases the tool and work piece contact temperature nearly 800^0C. PDA system was introduced to measure the droplet parameters of cold water mist jet system. A better improvement in surface finish and minimum flank wear was accomplished by using cold water mist jet in the machining of TC9 titanium alloy. Multi objective Jaya algorithm [8] was applied to achieve optimum parameters in the electro discharge machining process. Nano boric acid particle [2] mixed with coconut oil and SAE-40 was used in this MQL machining. Specific heat has a little dominant role to decide the surface roughness value of AISI 1040 stainless steel. Finally, Nano boric particle mixed with coconut oil makes the better finish of work piece and decreases cutting tool temperature and tool wear. [3] Develop a novelty method by implementing three different cooling modes. Extreme oil on water, internal oils in water, cryogenic air mixed with oils on water are the cooling conditions for machining compacted graphite cast iron. Chip morphology, tool wear under different working conditions was studied. In all the techniques it was obviously stated that wear increases with increase in cutting tool distance. The research reported that the cryogenic air mixed with oils on water was suggested because in this method, it reduces tool wear rate and surface roughness value compares with other methods. AlTiN [9] was used as one of the coated cutting inserts attains minimum nose wear during machining, especially at minimum cutting speed using minimal fluid application machining process. Built up edge formation, adhesion, wear reduces the life of the cutting tool. Finally the research concluded that AlTiCrN coating tools has 20-25% of tool life more than the other coated cutting tool. Tool wear mechanisms were analyzed by using scanning electron microscope (SEM) image. Vegetable oils are introduced in MQL systems, such as soya bean and blassocut [10]. The report stated that the contribution of soya bean in MQL environment aggressively reduces forces between tool and workpiece. GLARE 2B [11] was taken as a work piece involving drilling operation, surface roughness, torque and thrust force measurements were carried out and the surface topography image clearly shows the surface texture of the drilled area. Increase of flow rate in cryogenic process from 20ml/h to 60ml/h and air pressure from 1bar to 3bar reduces the cutting force by 2.5%. Liquid nitrogen acts as a coolant in cryogenic condition. Thrust force and torque continuously increased in dry machining by 20% compared with cryogenic machining. RSM using box-Behnken model applied by the researchers [12]. In their research the feed rate acts as a foremost parameter to decide surface roughness. [13] Presented a paper considered with different cutting tool insert style, cutting fluid, feed, cutting speed and depth of cut were considered as an input variable for machining AISI D3 tool steel. Deng's and WASPAS method was effectively employed to find optimal turning parameters. In their research it was concluded that DNMG as a cutting tool insert, and ground nut oil as a cutting fluid during machining gives prompt result in minimum surface roughness and tool wear. The residual stress prediction model was developed to study the temperature and cutting force in the machining TC4 alloy. The research gives clear information about the relationship between the lubrication flow rate and residual stresses during machining [14]. [18] parallel, perpendicular, cross pattern textured with PVD (Physical vapor deposition) coated tools is effectively involved in the machining of Ti6Al4V was investigated. The thermal imaging camera was employed to trace the tool tip temperature. Deform3D simulation assisted machining was compared with CNC turning with an experimental approach. Finally, in this research it was reported that the perpendicular texture, pattern tool increases the machinability and reduces cutting force during machining. [19] Deform 2D software was involved to study the cutting forces for various grades of titanium material. Analysis of variance (ANOVA) [25] was the suitable technique to identify the dominant factor of input variables to achieve the objective function in this research. Speed plays a vital role which affects the impact energy in brazing brass 319 joints. [17] Implemented the simulation technique for evaluating strain rates for Ti6Al4V and summarizes the results of strength and damage components by using Johnson-cook material. [20] Mainly focuses on the crater wear formation on carbide tool insert while machining of titanium alloy. Broken tool chip interface and plastically deformed edge of cutting tool was identified in SEM images due to high cutting speed of 150 m/min under dry condition.[21] presented a critical study about tool wear mechanism based upon cutting length versus depth of crater wear in microns. This study indicated that chipping of cutting edge was created more during machining. At the same time chipping was more created on the rake face of the cutting tool. [22] Conducted turning experiments under dry, pure MQL, nano MQL with 0.5 volume % with hexagonal boron nitride and nano MQL with 1 volume % with hexagonal boron nitride. Results show that cutting tool tip temperature and surface roughness value were gradually decreasing when using nano MQL with 0.5 volume % with hexagonal boron nitride and nano MQL with 1 volume% with hexagonal boron nitride during machining.[24] Analysis of variance (ANOVA) was effectively implemented to predict the contribution of input parameters in the Electrical Discharge Machining process and found the peak current act as the dominant factor that affect the surface roughness and the material removal rate.

Experimental Procedure

In the present study, all geared centre lathe was used for machining. Cutting Speed, feed and depth of cut were taken as input parameter and the response factors were considered as tool tip temperature and surface roughness. A lathe was equipped with an infrared thermometer and minimum quantity lubrication setup as a necessary equipment to carry out the experiment works and outcomes were obtained. In this machining process AISI D2 steel was considered as a work piece and coated CBN as a cutting insert material used for machining process. In each operation, cutting length was fixed as 70 mm.The infrared thermometer was connected in tool holder and focus towards work piece and tool tip cutting zone, to compute the tool tip temperature during the machining operation. The experiments were carried out by three categories, such as dry machining, minimum quantity lubrication machining with 10 millilitres (ml) /Hour (h) and 15 ml/h. The experimental setup is shown in Figure 1. The level of cutting parameters is given in Table 1.

Figure 1.Experimental setup

Table 1. Level of cutting parameters

Parameters	**Level with values**
Feed rate in mm/rev	0.15, 0.20, 0.25
Cutting speed in m/min	121, 182, 270
Depth of cut (mm)	0.5, 1.0, 1.5
Machining condition	Dry machining, Minimum quantity lubrication with 10 ml/h, Minimum quantity lubrication with 15 ml/h

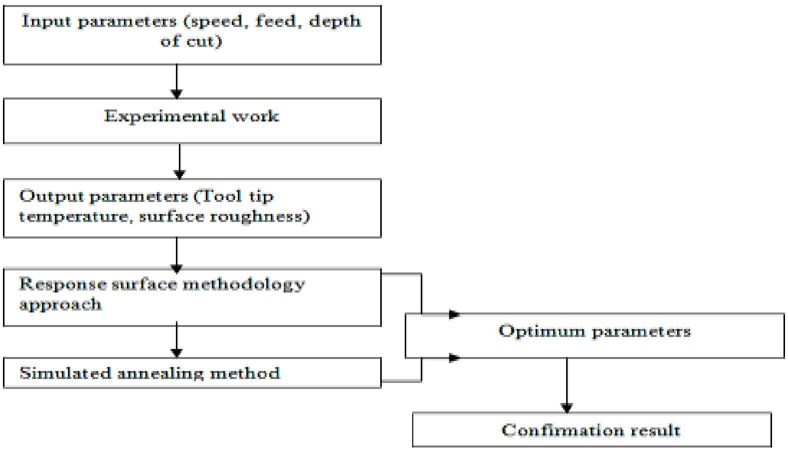


Figure 2. Flow chart of the machining process

The flow chart is represented in Figure 2. It shows the steps involved in this work to establish optimum output parameters such as surface roughness and tool tip temperature. In the first stage by using the input parameters, the out parameters were found by using an experimental setup. In the second stage by using response surface methodology, Box-Behnken model was applied and the quadratic regression model and predicted values are also found. The equations generated by ANOVA technique, were applied in the simulated annealing algorithm and the values are predicted. Optimal parameters for the response variables of tool tip temperature and surface roughness was found. Then the optimum values of the input variables to the corresponding response variables were found by comparing with the forecast values from response surface methodology and simulated annealing algorithm. Validation test was carried out, by using the optimum values achieved from the response surface methodology and simulated annealing algorithm. Tables 2 and 3 Show the result of output values of tool tip temperature and surface roughness in different machining conditions.

Table 2. Experimental values of tool tip temperature

Runs	**Speed (m/min)**	**Feed (mm/ rev)**	**Depth Of cut (mm)**	**Tooltip temperature in ^{0}c**			**Runs**	**Speed (m/min)**	**Feed (mm/ rev)**	**Depth Of cut (mm)**	**Tooltip temperature in ^{0}c**		
				Dry	**MQL (10ml/h)**	**MQL (15ml/h)**					**Dry**	**MQL (10ml/h)**	**MQL (15ml/h)**
1	121	0.15	0.5	47.9	35.8	41.1	**11**	182	0.2	1	53	42.5	40.5
2	121	0.25	0.5	47.3	47.4	44.7	**12**	182	0.2	0.5	48.6	42.4	42.5
3	121	0.15	1.5	63.7	36.1	42	**13**	182	0.25	1	53.5	48	42.1
4	121	0.2	1	52	43.6	42.5	**14**	182	0.2	1	53.6	42.9	40.3
5	121	0.25	1.5	63.3	47.2	45	**15**	182	0.2	1	54	42.6	40.2
6	182	0.2	1	53.4	43.1	40.1	**16**	270	0.15	0.5	54	37.8	34.8
7	182	0.2	1	53.2	42.3	40.1	**17**	270	0.25	1.5	67	49.2	38.1
8	182	0.2	1.5	64.6	43	40.4	**18**	270	0.15	1.5	65	37.5	35.6
9	182	0.15	1	53.8	36.8	38.9	**19**	270	0.25	0.5	51	49	37.9
10	182	0.2	1	53.6	42.5	40.2	**20**	270	0.2	1	55.1	43.4	36.8

Table 3. Experimental values surface roughness

Runs	**Speed (m/min)**	**Feed (mm/ rev)**	**Depth Of cut (mm)**	**Surface roughness in microns**			**Runs**	**Speed (m/min)**	**Feed (mm/ rev)**	**Depth Of cut (mm)**	**Surface roughness in microns**		
				Dry	**MQL (10ml/h)**	**MQL (15ml/h)**					**Dry**	**MQL (10ml/h)**	**MQL (15ml/h)**
1	121	0.15	0.5	3.65	3.18	3.91	**11**	182	0.2	1	3.74	3.23	3.52
2	121	0.25	0.5	3.75	3.18	3.69	**12**	182	0.2	0.5	3.48	2.91	3.33
3	121	0.15	1.5	4.4	3.86	4	**13**	182	0.25	1	3.72	3.21	3.41
4	121	0.2	1	3.89	3.38	3.98	**14**	182	0.2	1	3.7	3.21	3.55
5	121	0.25	1.5	4.21	3.86	4.21	**15**	182	0.2	1	3.69	3.15	3.52
6	182	0.2	1	3.75	3.16	3.55	**16**	270	0.15	0.5	3.14	2.67	2.7
7	182	0.2	1	3.71	3.19	3.5	**17**	270	0.25	1.5	3.94	3.39	3.42
8	182	0.2	1.5	4.19	3.81	3.84	**18**	270	0.15	1.5	3.91	3.36	3.25
9	182	0.15	1	3.68	3.19	3.61	**19**	270	0.25	0.5	3.18	2.71	2.56
10	182	0.2	1	3.7	3.33	3.6	**20**	270	0.2	1	3.39	2.81	2.69

2. RESULT AND DISCUSSION

3.1 Surface roughness and Tool tip temperature

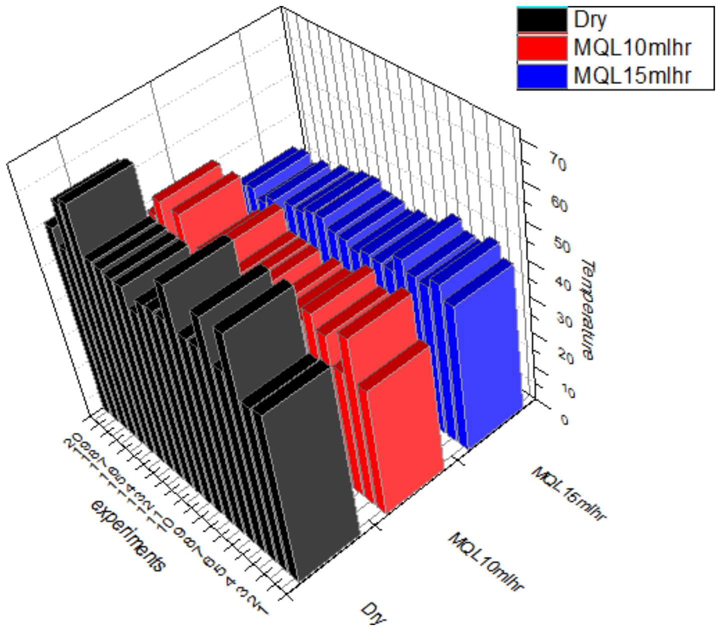


Figure 3. Comparison graph of the tool tip Temperature

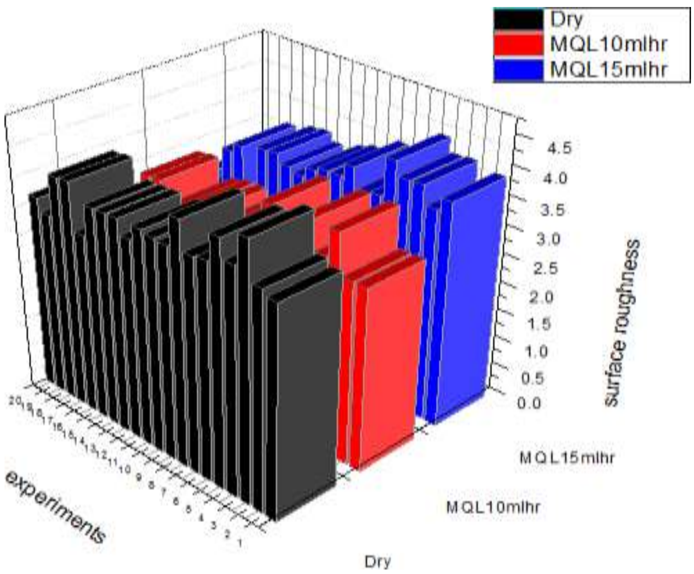


Figure 4. Comparison graph of the surface roughness

A Graphical illustration of the tool tip temperature and surface roughness are clearly represented in Figure.3 and Figure.4 respectively. It was clearly noted, rubbing action of cutting tool with work piece plays the most important role in deciding tool tip temperature. In dry machining tool tip temperature reaches 67^0c at maximum speed and highest depth of cut, it resembles more heat in between tool tip and work piece due to lack of lubrication in dry machining. Considered surface roughness in among three machining conditions, the minimum surface roughness value occurred at minimum quantity lubrication machining at a flow rate of 15ml/h. It was obviously stated that, when MQL is adopted in machining process it automatically gives better surface roughness to the machined part.

3.2. ANALYSIS OF VARIANCE

3.2.1 Model summary and regression equations:

ANOVA technique was implemented to check the competence and confirm the fitness of the model. In this model, Model summary of the all response factors shows that R-sq, R-squared (adjusted) R-squared (predicted) values are more than 0.85 for all the response models and the values are very closer to 1, which is preferable. Figure.5 shows the response optimizer plot that was generated by using response surface methodology. The optimization plot for the response variables of tool tip temperature and surface roughness for dry, MQL (10ml/h), MQL (15ml/h) was plotted. Desirability value of 0.9054 closer to 1 confirms the optimal values of minimum tool tip temperature and surface roughness at dry, MQL (10ml/h), MQL (15ml/h) was accomplished at 270 m/min, 0.15 mm/rev, and 0.5 mm depth of cut in Figure.5. Equation (1) – (6) generated by the regression model are used to predict the responses.

Model Summary -Temp (dry)

S	R-sq	R-sq(adj)	R-sq(pred)
0.690533	99.29%	98.65%	87.91%

Temp (dry) = 47.05 + 0.0443*speed - 90.6*feed + 9.94*doc - 0.000012* speed*speed + 157*feed*feed + 1.51*doc*doc - 0.0034*speed*feed - 0.01544*speed*doc + 24.89 *feed*doc (1)

Model Summary - SR (dry)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0372205	99.24%	98.56%	86.19%

SR (dry) = 3.548 -0.00366 speed + 1.47*feed + 0.856*doc - 0.000004 speed*speed - 2.42*feed*feed - 0.032*doc*doc + 0.00526*speed*feed + 0.001066*speed*doc - 1.534 *feed*doc (2)

Model Summary- Temp (MQL 10ml/h)

S	R-sq	R-sq(adj)	R-sq(pred)
0.501161	99.24%	98.56%	94.86%

Temp (MQL 10ml/h) = 12.04- 0.0252*speed + 198.6*feed + 2.38*doc + 0.000081 speed*speed – 217*feed*feed -1.26*doc*doc + 0.0076*speed*feed + 0.00101*speed*doc +0.29 feed*doc (3)

Model Summary- SR (MQL 10ml/h)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0662000	97.90%	96.01%	90.67%

SR (MQL 10ml/h) = 3.059 + 0.00012*speed - 0.94*feed + 0.549*doc - 0.000010*speed*speed + 1.8*feed*feed + 0.092 *doc*doc + 0.00233*speed*feed + 0.000020*speed*doc- 0.057 feed*doc (4)

Model Summary- Temp (MQL 15ml/h)

S	R-sq	R-sq(adj)	R-sq(pred)
0.625518	97.10%	94.49%	81.10%

Temp (MQL 15ml/h) = 36.95 - 0.0031*speed + 72.0*feed - 5.97*doc - 0.000084 *speed*speed- 73*feed*feed+ 3.64*doc*doc - 0.0335*speed*feed - 0.00046*speed*doc - 5.98 *feed*doc (5)

Model Summary- SR(MQL 15ml/h)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0654126	98.82%	97.75%	91.71%

SR (MQL 15ml/h) = 5.464 - 0.00539*speed - 6.06*feed - 0.742*doc - 0.000012 *speed*speed+ 3.9*feed*feed -0.048*doc*doc + 0.00195*speed*feed + 0.002925 *speed*doc + 3.899 feed*doc (6)

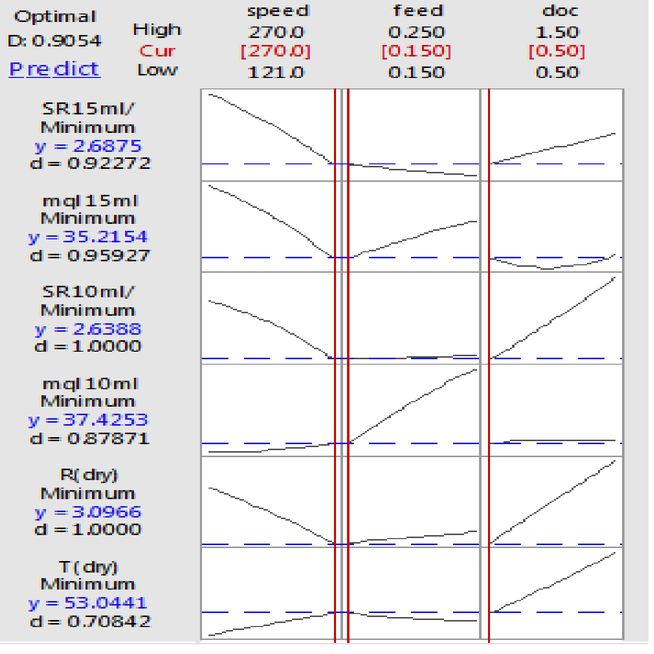


Figure 5. Response optimizer plot

3.3 SIMULATED ANNEALING

Simulated annealing is one of the best optimization methods for solving minimization and maximization optimization problems. Simulation annealing algorithm started with an initial solution and random modification was made in the current solution. The next step is to find a function value of a new solution. Comparison was made in between new solution to the current solution. A new point is generated in each iteration by employing a simulated annealing algorithm, which depends upon the objective function. The algorithm recognizes all the new generated points to attend the goal with definite probability. Matlab software was used to implement the simulated annealing algorithm to search and confine the optimum value for the regression equation (Eqn (1)-(6)) given in model summary and regression equations, generated by the response surface methodology. In each iteration simulated annealing found the best point that means minimum (or) maximum objective function value. Simulation annealing toolbox in Matlab 2010 software is used to get optimal values of surface roughness and tool tip temperature. The following parameters are set in the simulated annealing tool box to find the best optimal input variables of cutting speed, feed rate, and depth of cut that lead to find lowest surface roughness and tool tip temperature for the different machining conditions:

Lower bound	=	{121, 0.15, 0.5}
Upper bound	=	{270, 0.25, 1.5}
Annealing function	=	fast annealing
Temperature function	=	Exponential Temperature

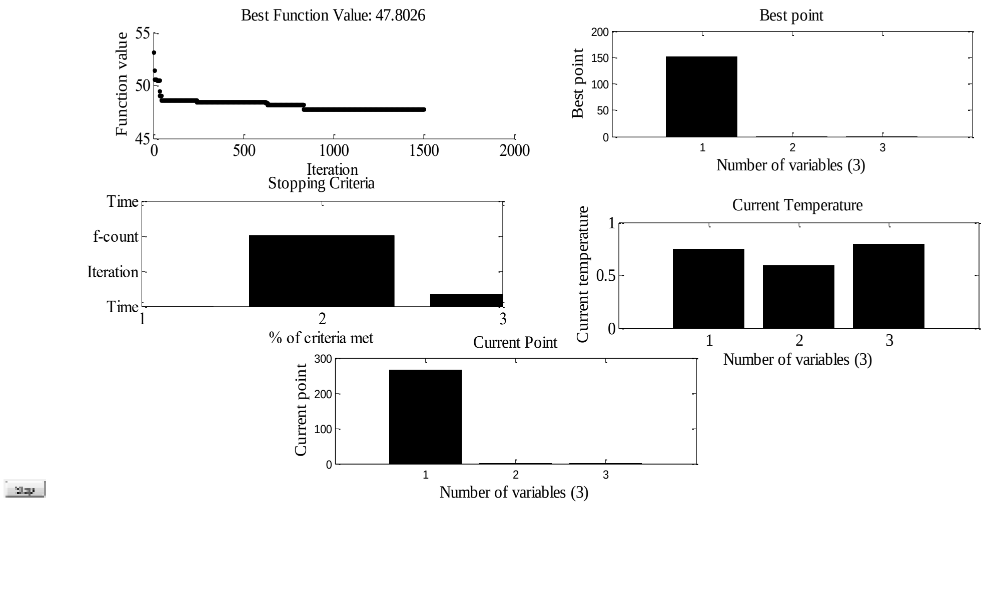


Figure 6. Tool tip temperature (dry machining) from simulated annealing method

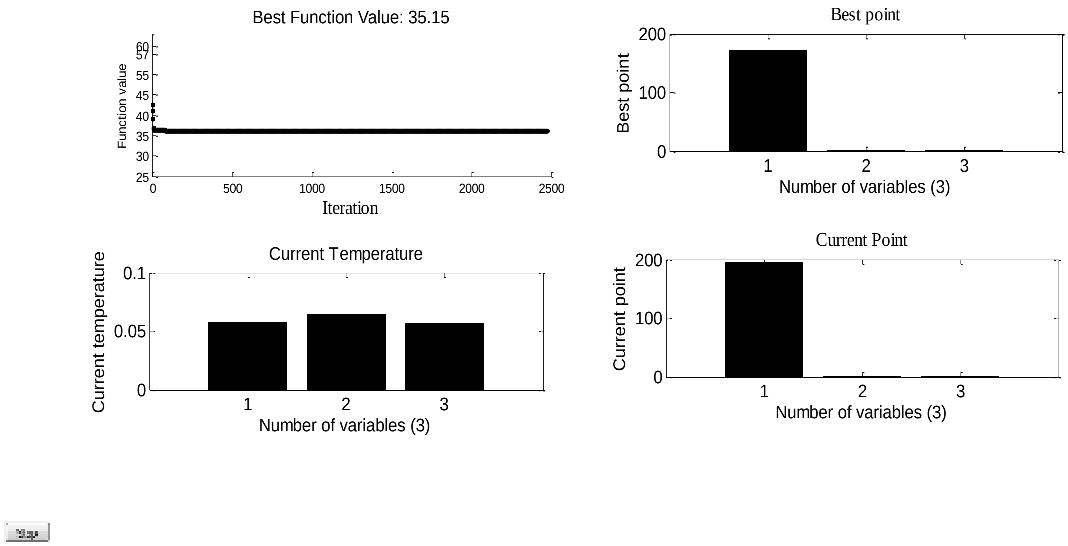


Figure 7. Tool tip temperature (MQL 10ml/h machining) from simulated annealing method

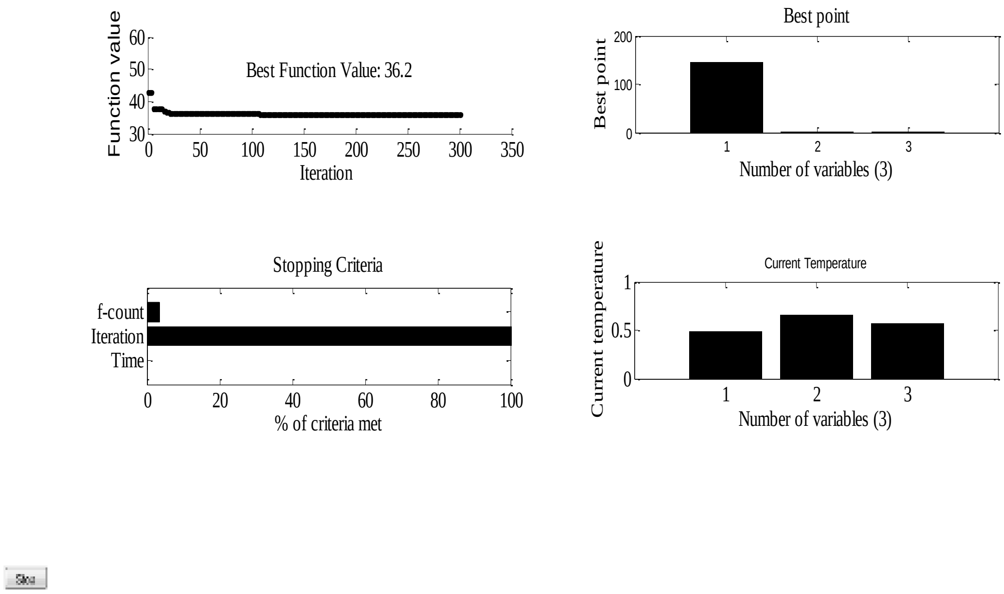
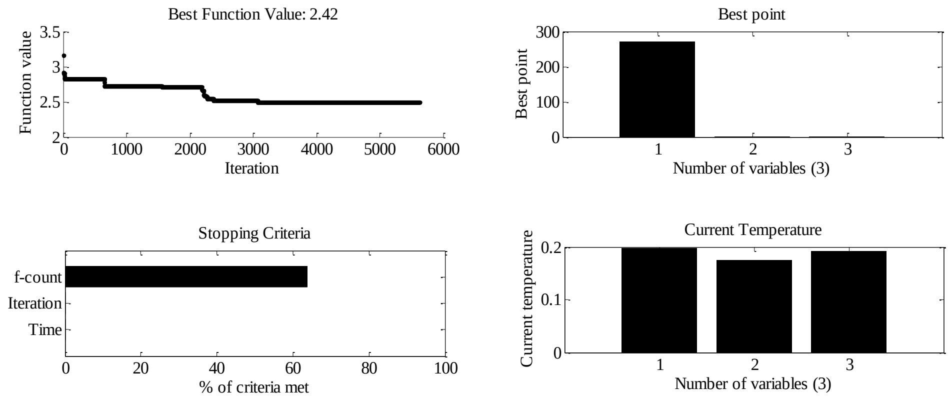
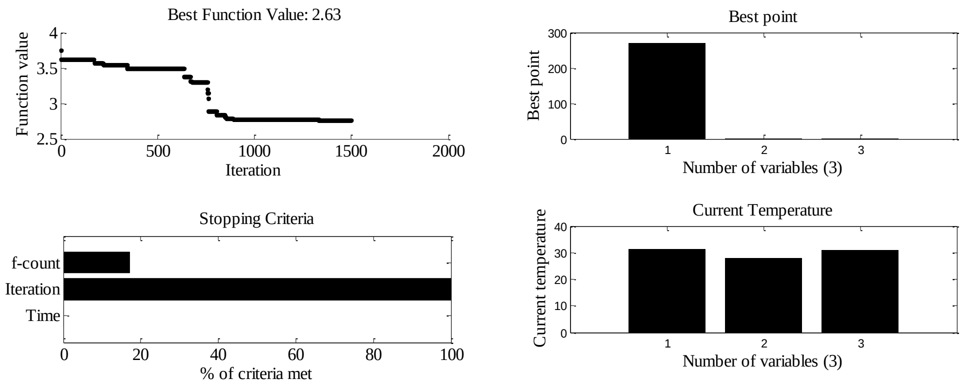


Figure 8. Tool tip temperature (MQL 15ml/h machining) from simulated annealing

(a)



(b)



(c)

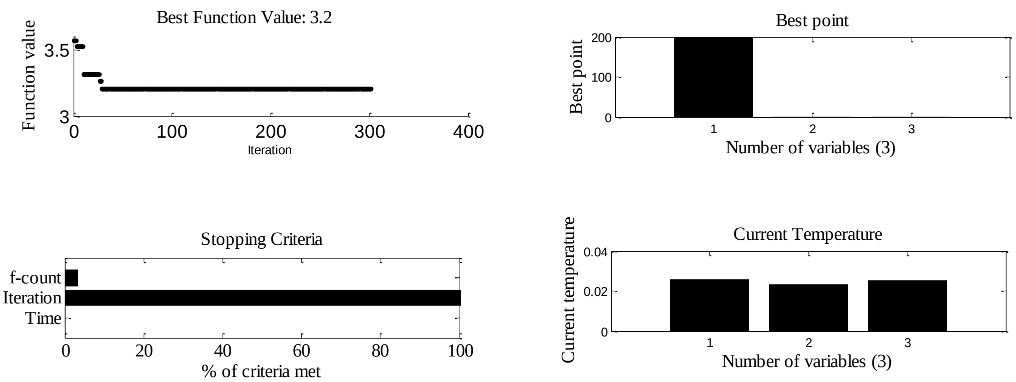


Figure 9. (a) Surface roughness value of MQL 15 ml/h machining from simulated annealing method, (b) surface roughness value of MQL 10 ml/h machining from simulated annealing method, (c) surface roughness value of dry machining from simulated annealing method

3.4. Simulated Annealing Results

It was observed that the least tool tip temperature was achieved with minimum quantity lubrication machining by using 10 ml/h. The lowest surface roughness value was noticed at the flow rate of 10 ml/h in minimum quantity lubrication machining process. The minimum tool tip temperature for the dry, MQL with 10ml/h, MQL with 15 ml/h was clearly represented in Figures 6, 7 and 8 respectively. The surface roughness value was predicted by using a simulated annealing methodology presented in Fig. 9 (a), (b), (c) respectively. The simulated annealing method predicts the best function value of surface roughness, when the iteration was increased more than 300th iteration.

Figure 6.Show the value of tool tip temperature of dry machining using a simulated annealing algorithm. The function value of the tooltip temperature was gradually decreased and it was reached minimum temperature of 47.8^0c at 1500th iteration. From the figure 7 and figure 8, it was clearly understand that the prediction of tooltip temperature by using the simulated annealing method in MQL machining with 10ml/h reaches minimum at 2000th iteration and the MQL machining with 15ml/h reaches the minimum value of 36.2^0c at 300th iteration.

3.5 Tool Wear Mechanism and chip morphology

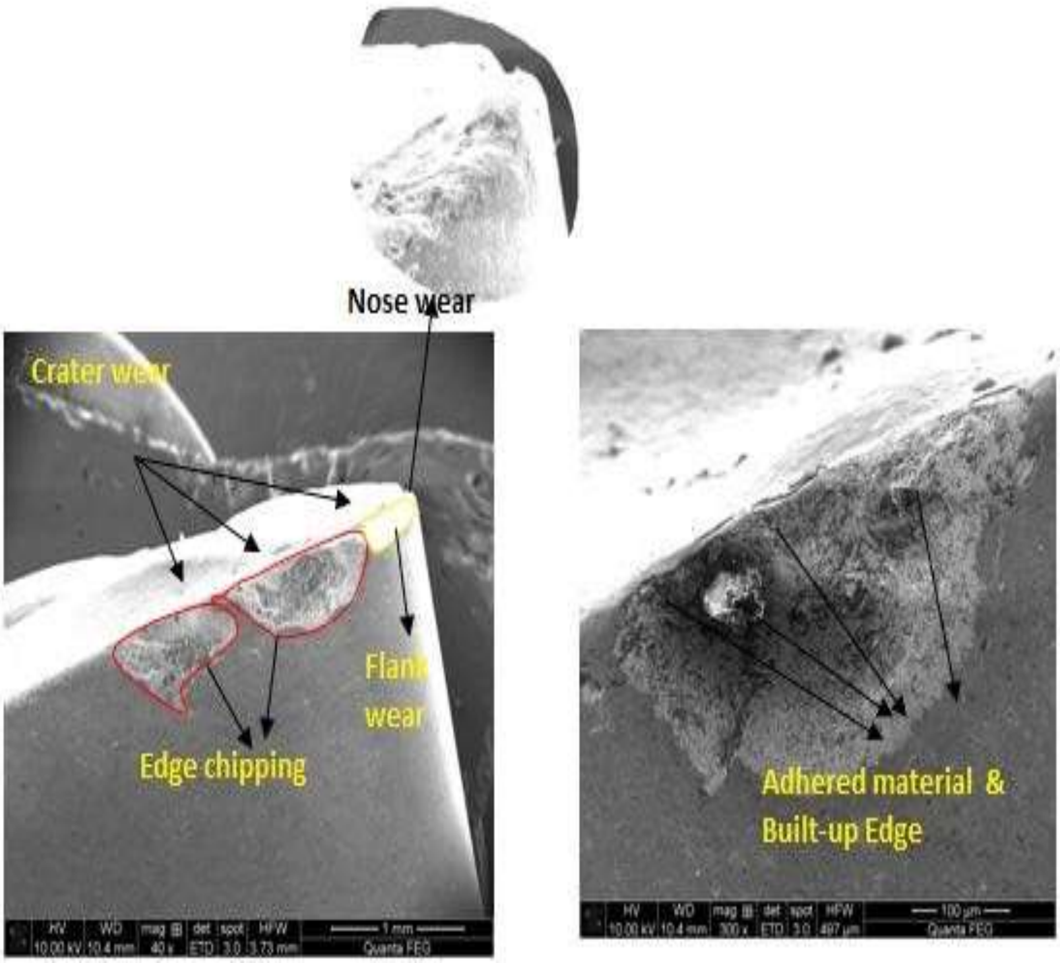


Figure 10. SEM micrograph image of cutting tool with wear region at a speed of 270 m/min, feed rate of 0.25mm/rev and a depth of cut of 1.5 mm (Dry machining)

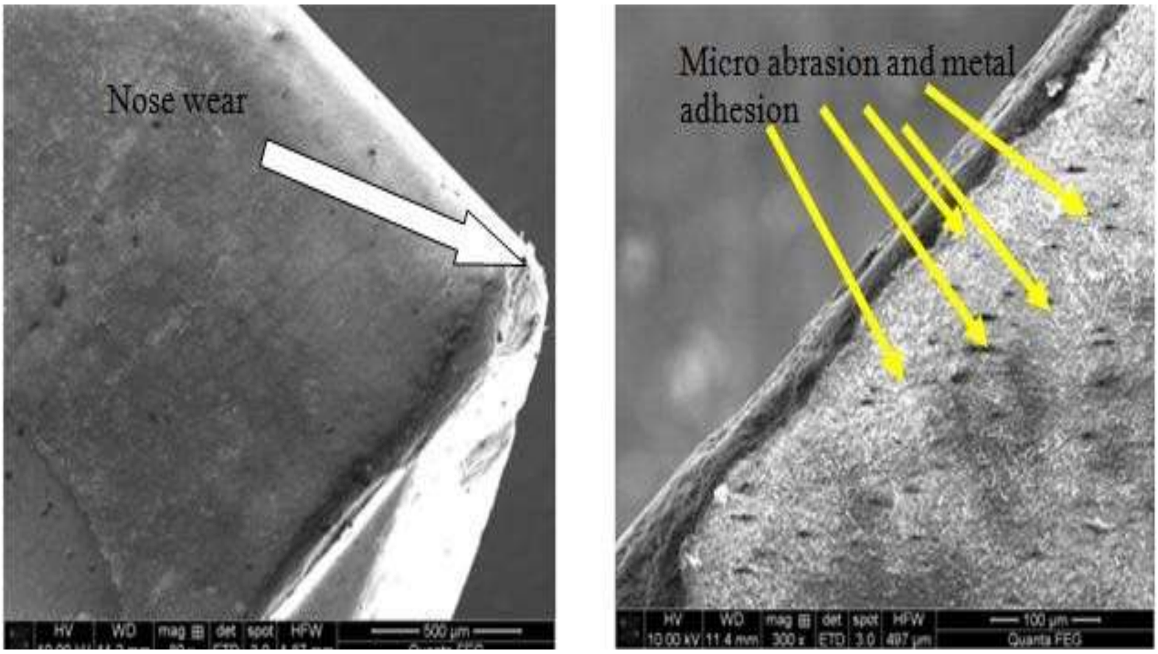


Figure 11. SEM micrograph image of the cutting tool with minimum quantity lubrication machining (15 ml/h) with wear region at a speed of 270 m/min, feed rate of 0.25 mm/rev and a depth of cut of 1.5 mm

		
Dry machining,	**MQL machining with 15ml/h**	**MQL machining with 10ml/h**
cutting speed = 270m/min, feed rate = 0.15 mm/rev, depth of cut = 0.5mm		

Figure 12. Chip morphology

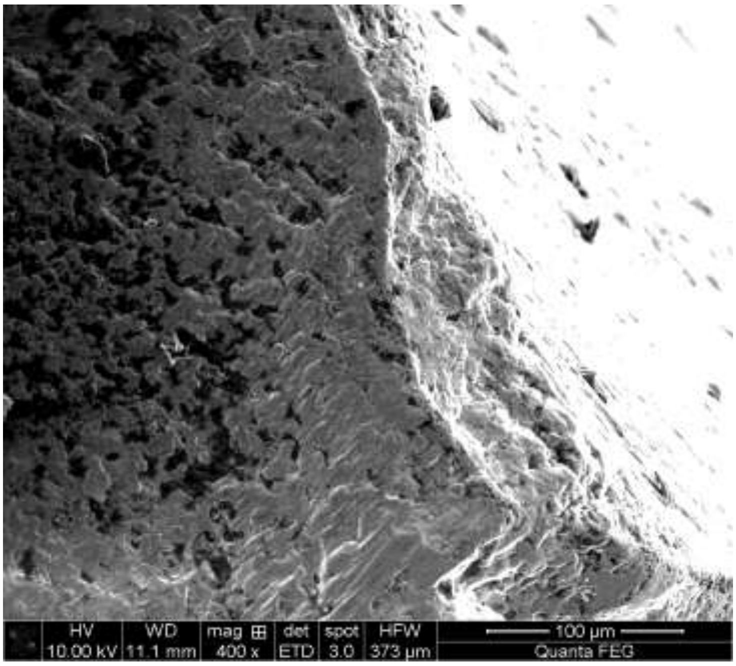


Figure 13. SEM image of worn region of cutting insert in MQL machining with 10 ml/h at a cutting speed of 270 m/min

[14] Stated that when the depth of the crater on cutting tool increases, it develops mechanical stresses and create plastic deformation on cutting edge during machining.[15] Clearly explained in his research paper, due to severe adhesion creates on flank face forms a flattened tool flank face and it increases the cutting zone area Furthermore, it was confirmed that the more cutting temperature creates cutting edge chipping and more adhesion layer on the tool Flank face area. [16] Concluded that built-up edge and built up layer mostly damage the cutting tool for a particular time period during the machining and adhesion acts as the most dominant wear mechanism which affects the tool life. SEM image of the worn-out insert during the dry machining is clearly presented in Figure 10. Due to the high cutting speed and depth of cut, edge chipping has occurred. The edge chipping creates the worst surface finish in the machined part. The maximum contact zone temperature creates more cutting forces and makes edge chipping along the edge of the cutting tool. Due to the maximum temperature on chips, it passes on the top face of the cutting insert create more crater wear, which is clearly indicated in the SEM image in Figure 9. Weldment of chips is adhered in the edge and face of the cutting tool and built-up edge was also created on the cutting tool. Groove on the nose point of the cutting tool creates the worst surface finish in the machined part. Micro abrasion marks and metal adhesion are clearly indicated in Figure 11.It was obviously stated that there are no crater wear and flank wear because of the minimum quantity of lubrication machining with 15 ml/h. It was evident that the surface finish value was minimal at the cutting speed of 270 m/min, feed rate of 0.25 mm/rev and a depth of cut of 0.5 mm. Figure 11 clearly shows in MQL machining that the nose wear was slightly created because of the tool tip temperature and sliding action in between the tool nose and a workpiece. Chip fragments, micro particles, chip debris were formed over the coated tool insert was discussed in [23] Micro abrasive particles were spotted due to wear was clearly presented in Figure 11 and that was already reported in [23].

Figure 12 shows the chip morphology of the chips created under three different working conditions. In dry machining conditions, at the optimal machining conditions, chip was generated and identified in the form of serrated and discontinuous chip due to the excessive wear and cutting force between the tool and work piece. In the MQL machining with 15ml/h, chips were identified in the form of spring and it was curled because of air and oil mixed together by employing the MQL technique and thus reduced the temperature and improved surface finish of the work piece. Minimum quantity lubrication machining with 10ml/h generated chips in the curled form and it was identified with serrated tooth formed on chips since that temperature and surface roughness value were slightly increased compared to the MQL machining with 15ml/h. In Figure.12 it was observed that the chip length decreases, due to increase in cutting speed under the dry machining conditions. This study was confirmed by [26] and their study on machining of 7075-T6 aluminum alloy. Better chip flow was occurring in the MQL with 15ml/h indicated in Figure12. As a result of this condition chip formation was smoother, similar to the work previously investigated in [27]. Figure 13 shows the high resolution SEM image of cutting insert after the MQL machining with 10ml/h. Due to the rubbing action between cutting tool and a workpiece, slight flaking and flank wear were occurred. Crater wear and abrasion marks were also identified due to high cutting speed and chip flow in Figure 13. Similar wear mechanism was also discussed in [28].

3. CONCLUSION

It was evident that the minimum tool tip temperature and surface roughness was achieved in the minimum quantity lubrication machining process at the flow rate of 10ml/h. Cutting zone temperature among the cutting tool was drastically reduced in minimum quantity lubrication machining compared to the dry machining process. Results of surface roughness values given in table 3 shows that the better surface improvement of 15% was achieved in minimum quantity lubrication machining compared with dry machining process. The cutting speed and depth of cut plays an imperative role to fix the tooltip temperature and surface roughness in the machining process. In the confirmation test, results show very promising results of surface roughness and tool tip temperature values compared to other techniques obtained at cutting speed of 270 m/min and feed rate of 0.15 mm/rev and the depth of cut of 0.5 mm in minimum quantity lubrication shown in Table 4. Less tool wear was identified in figure 11, reveals that the minimum quantity lubrication machining method was the best method for reducing wear of the cutting tool as well as to improve the surface finish of the work piece. Chip morphology was also studied and discontinuous chip with serrated teeth was formed in dry machining at high cutting speed. The MQL machining provides enhanced surface quality of the work piece and also diminishes the tool wear in cutting insert. In future cutting chip thickness ratio, injector position towards the work piece during the MQL machining, hybrid nano MQL machining will be recommended for investigation.

Table 4 Output Parameters

Output parameters	Response surface methodology	Simulated annealing	Confirmation test
Surface roughness	2.68 microns	2.42 microns	2.9 microns
Tooltip temperature	35.2^{0}C	35.15^{0}C	38^{0}C

To apply this concept in any industries, the quality of the products can be easily achieved. The good dimensional accuracy and longer tool service life can be achieved.

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