International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. XI, No. 2 / 2019

MACHINABILITY STUDIES ON EN47 SPRING STEEL BY OPTIMIZATION TECHNIQUE DURING DRY AND WET CONDITION

Vasu Mallesha[1], Shivananda Nayaka Hanumanthappa[1], Pradeep V Badiger[2], Vinyas Mahesh[2]

[1]Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, Mangaluru 575025, India
[2]Composite Research: Experimentation, Analysis and Modeling (CREAM) lab, Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore, India – 560064

Corresponding author: Vasu Mallesha, vasu.m.manu@gmail.com

Abstract: EN47 Spring steel is a hard material having a hardness of 45-48HRC. EN47 material possesses low thermal conductivity and suitable for oil hardening and tempering. Hardened spring steel offers excellent toughness and shock resistance, suitable alloy for automobile applications. In this experimental study, to optimize the process parameters such as cutting speed (V_c), feed rate (f) and depth of cut (a_p). In order to minimize the surface roughness (R_a), tool tip temperature (T) and tangential cutting force (F_z) during turning of spring steel by coated tungsten carbide cutting tool insert under dry and wet condition. Experiments are conducted based on the design of experiment using full factorial design (3^3: three factors and three levels) L_{27} orthogonal array. From the experimental work, result reveals that surface roughness (R_a) influenced by (V_c and f). Tangential cutting force (F_z) influenced by (f and a_p). Tool tip temperature influenced by (V_c and a_p). The comparison have been done between dry and wet condition and the results reveal that under wet condition surface roughness (R_a) and tool tip temperature (T) is reduced by 22.59% and 21.29% respectively. Less difference was observed in cutting force (F_z) during dry and wet machining.

Key words: Spring steel, Tool tip temperature, Carbide tool, Surface roughness, Design of experiment, Cutting force, Full factorial design

1. INTRODUCTION

EN47 Spring steel is suitable for oil hardening and tempering, same are used in this condition it combines spring characteristics with good wear and abrasion resistance. Applications are involved such as manufacturing of die, leaf spring for a heavy vehicle, crankshaft, spindles, pumps and steering knuckles and many general engineering applications. Some of the literature is summarized on turning process performed using optimization technique. Gaitonde et al in his research work AISI D2 cold work material using three different ceramic tool inserts CC650, CC650WG, and GC6050WH, turning process is carried out on this for setting different V_c, f and a_p. Experiments conducted based on full factorial design (FFD), output responses are machining force, surface roughness, tool wear and specific cutting force are measured. He concludes that the CC650WG wiper insert exhibits better tool wear and surface roughness, while the CC650 conventional insert is useful in minimizing the machining power, machining force and specific cutting force [1]. Abhang and Hameedullah investigated that power consumption on turning operation, EN31 workpiece and tungsten carbide insert are used. Acquire data and analyze using ANOVA technique, 1st and 2nd order power consumption prediction model is established by using RSM. He concludes that 2nd order model is more accurate and this can be used industries for setting cutting parameters for minimum power consumption and increasing productivity [2]. Aruna and Dhanalakshmi reveal that optimization technique that reduces cost and time of machining. For his research work nickel-based super alloy Inconel 718 are workpiece material with cermet insert tool are used and investigates surface roughness based on response surface method and developed the 2nd order, quadratic model. Experiments are validated with predicted value and are in good agreement [3]. Mahamani et al investigates study of input parameters on surface roughness and cutting force, turning the process on AA2219-TiB_2/ZrB_2 with uncoated tungsten carbide. The cutting parameters are V_c, f and a_p, the L_{27} orthogonal array was used for experiments and the regression models for the responses are developed. From the experimental work, concludes that feed rate influencing more on surface roughness and cutting force confirmed by ANOVA [4]. Ahmed et al investigated the feed force and radial force by using Taguchi design approach. In his research work, the turning process is carried out on mild steel with HSS tool. Three cutting parameters was chosen namely V_c, f and a_p taguchi L_9 OA are employed. Results are analyzed by ANOVA and the quadratic model was developed with the help of regression analysis. From his research work, he concludes that percentage contribution of the depth of cut and cutting speed are more significant and is affecting feed and radial force [5]. Kosaraju and

Chandraker studied machinability characteristics of MDN350 steel with a cemented carbide insert. Experiments conducted based on Taguchi L_9 orthogonal array. Input parameters are V_c, f and a_p are optimized on cutting force and surface roughness. He concludes that cutting speed is influencing more on cutting force and feed rate influencing more on surface roughness [6]. Bensouilah et al investigates the surface roughness and cutting force. Taguchi L_{16} orthogonal array was employed. AISI D3 cold work tool steel is workpiece material and CC6050 and CC650 are ceramic inserts used. ANOVA, S/N ratio, and RSM were adopted for acquiring data. He concludes that coated CC6050 is better for surface roughness and uncoated CC650 ceramic insert useful for cutting force [7]. Researchers identified output responses like cutting forces feed force, thrust force and tangential force (F_x, F_y and F_z), surface roughness (R_a), tool wear (TW), material removal rate (MRR) and cutting temperature (T) for different material like AISI series materials, Inconel series materials and nickel-based alloys etc., using optimization technique.
From the literature survey, a limited work has been reported on machinability studies of EN47 material. Hence present article aims at is optimize the cutting condition on output performance. Experiments are conducted based on an L_{27} full factorial design orthogonal array. The results of the research lead a bench mark for future work such as hot machining and cryogenic machining etc. In this present work turning process carried out on EN47 spring steel with coated cutting tool insert during dry and wet condition. The effect of input parameters such as cutting speed (V_c), feed rate (f), and depth of cut (a_p) on tangential cutting force (F_z), the surface roughness (R_a) and tool-tip temperature (T) are analyzed using statistical techniques.

2. EXPERIMENTATION

In this present work, EN47 spring steel is used, workpiece dimension having a length of 170 mm and diameter 30mm (L/D ratio <10 as per ISO 3685). Experiments are conducted with dry and wet condition using precision panther lathe machine, having spindle speed ranges from (30-1250)rpm. The chemical composition of EN47 spring steel is shown in Table 1, confirmed by spectroscopy.

Table 1. Chemical composition spring steel EN47

C	Mn	Si	S	P	Cr	Fe
0.45-0.55	0.50-0.80	0.50 Max	0.40	0.40	0.80-1.20	Rest

Cutting parameters considered were V_c, f and a_p. In practice, design of experiment (DOE) method has been used quite successfully in several industrial applications as in optimizing manufacturing processes. An orthogonal array is required which is more efficient in handling a large number of experiments with different variables than traditional factorial design and it reduces number of experimental trials [8-11].
Experiments were designed and conducted based on L_{27} full factorial design optimization technique. In design of experiment (DOE), 3^3 three factors and three levels are considered [12–16]. Cutting parameters are selected based on literature survey and cutting condition obtained from the tool manufacturer and is depicted in Table 2. Turning process was carried for both the condition of dry and wet. During turning process cutting forces are measured using Kistler lathe tool dynamometer (Type 9257B) acquiring data using the Dynoware software. Simultaneously tool tip temperature is also measured by infrared based thermal heat gun (Pyrometer). After machining surface roughness is measured by Mitutoyo Talysurf SJ301 readings are measured at distinct locations on the machined surface to minimize error.

Table 2. Cutting condition and their levels

SL No	a_p [mm]	V_c [rpm]	f [mm/rev]
1	0.1	625	0.046
2	0.2	796	0.093
3	0.3	1250	0.14

3. RESULT AND DISCUSSION

The output response of F_z, R_a and T has been reported in Table 3. From design expert and minitab software tool to analyze data systematically.

Table 3. Output responses during dry and wet condition

F_z Dry	R_a Dry	T Dry	F_z Wet	R_a Wet	T Wet
54.39	2.81	39.6	52.87	2.43	23.78
89.6	3.66	46.2	85.23	3.31	29.9
102.4	4.58	45.5	98.46	4.21	31.8
51.52	2.76	40.2	49.17	2.29	24.56
61.34	3.58	51.1	58.23	3.21	35.78
104.8	4.42	61.1	103.56	3.89	47.23
115.6	1.38	92.6	114.79	1.01	75.58
177.7	1.46	72.8	174.98	1.1	55.63
181.7	1.66	85.3	179.63	1.27	68.2
46.39	2.96	55.5	45.23	2.61	41.9
61.53	3.89	52.4	59.75	3.54	38.87
42.79	4.66	53.1	40.59	4.33	39.83
39	2.92	43.8	36.88	2.57	27.84
43.9	3.23	45.2	42.16	2.8	29.9
50.5	3.58	48.1	48.76	3.21	34.1
74.2	1.6	116	72.13	1.23	102.5
167.5	1.72	121	160.76	1.34	105.69
232.3	1.81	123	229.98	1.41	107.97
135.1	3.1	52.6	124	2.74	36.5
201.4	4.4	55.6	196.2	4.03	41.87
245.8	5.4	60.8	239.78	5.04	44.6
127.4	2.9	49.6	122.83	2.53	37.89
206.8	4.19	58.5	202.96	3.83	44.88
264.2	4.65	52.4	260.75	4.26	46.19
117.6	0.8	130	115	0.86	114.76
171.2	1.2	125	165.82	0.98	116.9
238.9	1.5	97.5	232.75	1.06	115.89

3.1 Analysis of Variance

Analysis of variance (ANOVA) is helped to identify significant factor for output performance and this is a computational technique that allows estimate relative contribution of each input parameters to the output performance. Using mathematical models, the process is validated. These models are developed only by significant term influencing the process. Using ANOVA results the significance of the output response is calculated from the probability value (P-value) at 95% confidence level. If the P-value less than 0.05 then obtained model is significant. Table 4 and Table 5 represent the summary of ANOVA for cutting force, surface roughness and tool tip temperature during dry and wet condition respectively. It is observed that obtained models are adequate in all the cases P-value is less than 0.05 and models are significant.

Table 4. Summary of ANOVA for Fz, Ra, T during dry condition

	SS	DoF	MS	F-Value	P-value
F_z	119463.31	9	13273.7	13.01	0.000
R_a	41.96	9	4.66	57.4	0.000
T	21407.48	9	2378.61	23.81	0.000

Table 5. Summary of ANOVA for Fz, Ra, T During wet condition

	SS	DoF	MS	F-Value	P-value
F_z	115792.15	9	12865.79	12.7	0.000
R_a	40.12	9	4.46	66.16	0.000
T	25177.26	9	2797.47	40.39	0.000

3.1.1 Analysis of cutting force (F_z)

Cutting force is one of the major significant factor in machinability study. Cutting forces are representative data to characterize machining operations. In higher cutting force it affects machined surface, reducing tool life and reducing the production. Therefore, cutting forces predictive models are useful and it is possible to optimize them by considering new parameters. The optimization technique is required to minimize cutting forces by setting proper selection of cutting condition. Mainly three cutting forces namely feed force (F_x), thrust or radial force (F_y) and tangential or main cutting force (F_z). Tangential force is the main cutting force and considered experimental work for analysis.

From Table 6 and Table 7 analysis of variance (ANOVA) for F_z are influenced by f, V_c and a_p. Machining of EN47 spring steel with coated carbide tool insert during dry and wet condition, feed rate has more influence on cutting force. This is due to increasing feed rate produce more friction between tool and the workpiece; this leads a higher cutting force during machining. Contact area between the tool and workpiece is more during higher feed rate, thus frictional force occurring at tool-chip interface is increased [17].

Table 6. Analysis of variance for cutting force (F_z) during dry condition

	SS	DoF	MS	F-Value	P-value
f	29931.5	1	29931.5	29.33	0.000
V_c	13739.29	1	13739.29	13.46	0.002
a_p	26183.4	1	26183.4	25.66	0.000

Table 7. Analysis of variance for cutting force (F_z) during wet condition

	SS	DoF	MS	F-Value	P-value
f	29729.32	1	29729.32	29.34	0.000
V_c	14096.88	1	14096.88	13.91	0.002
a_p	24290.42	1	24290.42	23.98	0.000

Further, in higher depth of cut workpiece are more resistant to deform and which require large amount of energy, chip thickness is increased in higher depth of cut of material [18]. Hence depth of cut and feed rate is influencing more on cutting force.

3.1.2 Analysis of surface roughness (R_a)

Surface roughness is one of the major output responses of machinability studies. A better surface finish is eliminating number of process like honing, lapping and buffing etc. Surface roughness influence coefficient of friction, corrosion resistance, fatigue strength, and wear rate of the machined components. It is essential to select proper selection of cutting parameters during machining and some of the factor will affect the machined surface it may tool variables and workpiece variables. Tool variables includes tool vibration, nose radius, coating material, tool base material, tool geometry, tool point angle, tool overhang etc. Workpiece variables include hardness of the work material, chemical and mechanical properties of workpiece and input parameters of V_c, f and a_p. For achieving better surface finish, it is necessary to take appropriate cutting condition as well as proper selection of tool and work material.

From Table 8 and Table 9 analysis of variance (ANOVA) for R_a is influenced by V_c and f. which leads better surface finish. Furthermore, higher feed rate leads a higher surface roughness this is due to increased feed rate, tool movement forms helical furrows and these furrows are wider and deeper which reduces surface roughness value (R_a) of machined surface similar results was observed by Bensouilah [7]

Table 8. Analysis of variance for Surface roughness (R_a) during dry condition

Dry R_a	SS	DoF	MS	F-Value	P-value
A-f	5.41	1	5.41	66.58	0.000
B-V_c	27.7	1	27.7	341.11	0.000
C-a_p	0.08	1	0.08	0.94	0.346

Table 9. Analysis of variance for Surface roughness (R_a) during wet condition

Wet R_a	SS	DoF	MS	F-Value	P-value
A-f	4.62	1	4.62	68.65	0.000
B-V_c	26.84	1	26.84	398.42	0.000
C-a_p	0.23	1	0.23	3.46	0.080

3.1.3 Analysis of tool tip temperature

Cutting temperature obtained at machining zone there are three distinct sources of heat in metal cutting there are a) shear zone b) chip tool interface c) work tool interface. 60% of energy developed in chips, 30% in tool and 10% in work material. In metal cutting, heat will be generated between tip of tool and workpiece. Increased cutting speed elevated higher temperature in the cutting zone. Moreover, higher temperature of cutting tool tends thermal softening of work material achieve better surface finish. Increased tool tip temperature form tool wear and reduced tool life. The optimization technique requires minimize tool tip temperature and to reduce tool wear by setting proper selection of cutting parameters.

Table 10. Analysis of variance for tool tip temperature during dry condition

T	SS	DoF	MS	F-Value	P-value
f	1.34	1	1.34	0.01	0.909
V_c	13994.65	1	13994.65	140.07	0.000
a_p	1467.89	1	1467.89	14.69	0.001

Table 11. Analysis of variance for tool tip temperature during wet condition

T	SS	DoF	MS	F-Value	P-value
f	110.96	1	110.96	1.6	0.223
V_c	15846.15	1	15846.15	228.79	0.000
a_p	2973.92	1	2973.92	42.94	0.000

From Table 10 and Table 11 analysis of variance (ANOVA) for tool tip temperature are influenced by V_c and a_p. Tool tip temperature increased by increasing cutting speed and followed by depth of cut. Feed rate having less significant in the model. Tool tip temperature increases with cutting speed increase [19]. In higher cutting speed, cutting force will be reduced and surface roughness will decrease, work material point of view higher cutting speed is benefited it will achieve better quality of product but tool point of view high cutting speed will affect the tool, which leads to tool wear, due to tool wear, tool vibrations will occur and it reduce tool life.

3.2 Main Effect Plots

Main effect plot is a graphical representation of each individual factor for output response. The highest slope tends more significant in model. The optimal cutting conditions are identified by main effect plots [20]. From the Figures 1-3 observed that main effects plot for F_z, R_a and T using coated tool insert during dry and wet condition. From the Figures 1(a) and (b) it is observed that cutting force are influenced by depth of cut (a_p) and feed rate (f). Feed rate (f) shows the highest slope, followed by depth of cut (a_p) and cutting speed (V_c) having less significant.

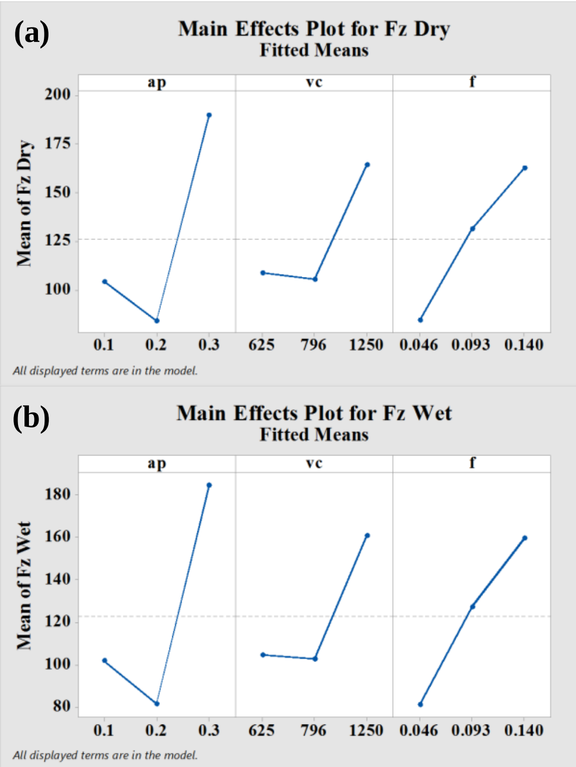


Fig. 1. Main effect plot for cutting force during dry (a) and wet condition (b)

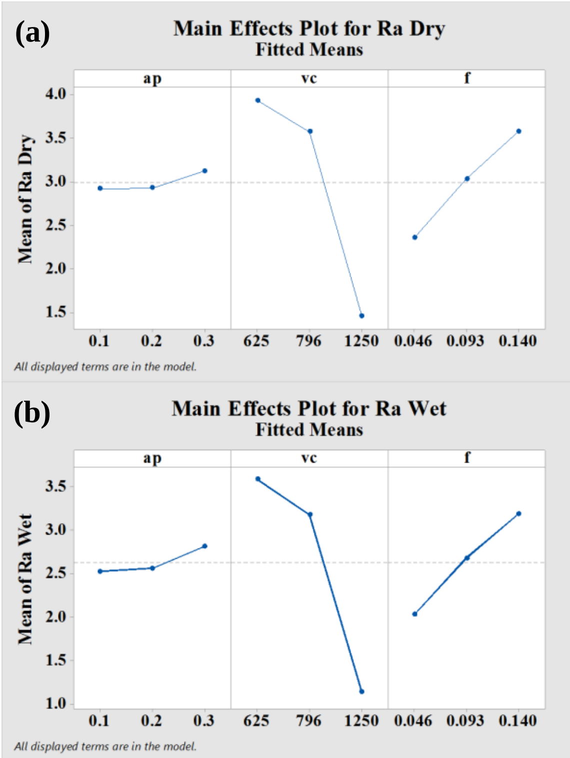


Fig. 2. Main effect plot for surface roughness during dry (a) and wet condition (b)

From the Figures 2(a) and (b) surface roughness (R_a) influenced by cutting speed (V_c), followed by feed rate (f) and depth of cut (a_p) having less significant in both the condition. From Figures 3(a) and (b) it is observed that cutting speed (V_c) influences more on tool tip temperature, second influencing factor depth of cut (a_p) and feed rate (f) having less significant.

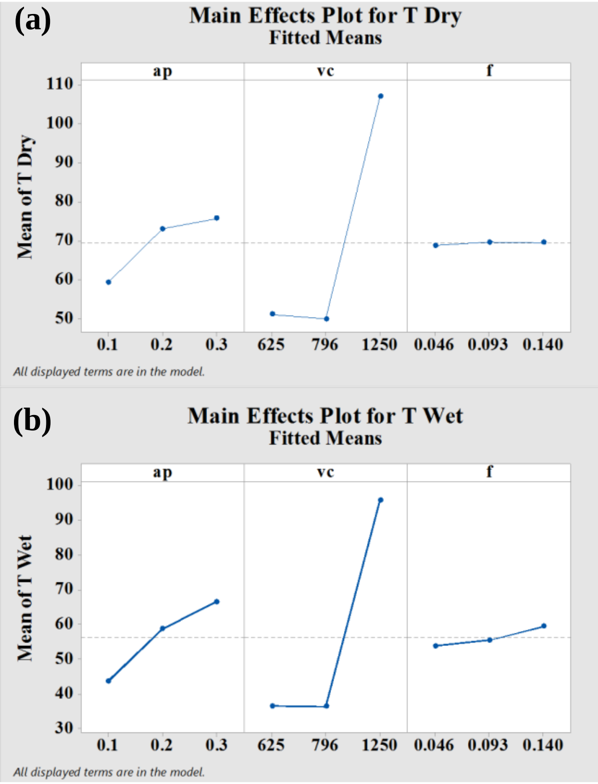
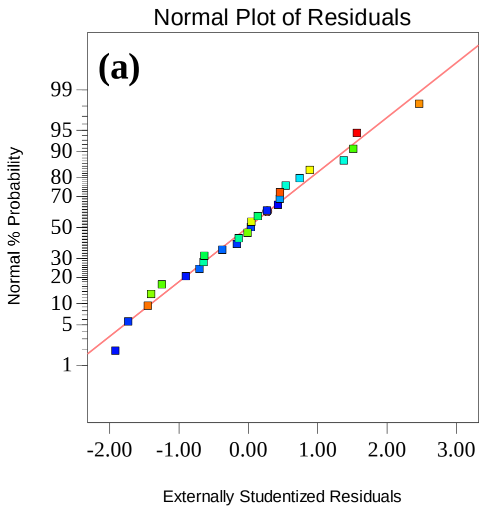


Fig. 3. Main effect plot for tool tip temperature during dry (a) and wet condition (b)

3.3 Normal Probability Plot

Normal probability plot indicates that, all points are fall on straight line which represents errors are equally distributed in model. From Figure 4 to Figure 6 normal probability plot for F_z, Ra and T during dry and wet condition similar trends are observed from Chabbi et al [21]. So obtained models are adequate.



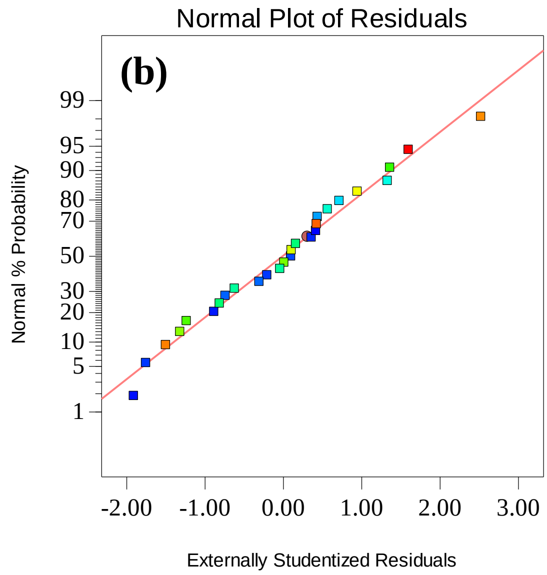


Fig. 4. Normal probability plot for cutting force during dry (a) and wet condition (b)

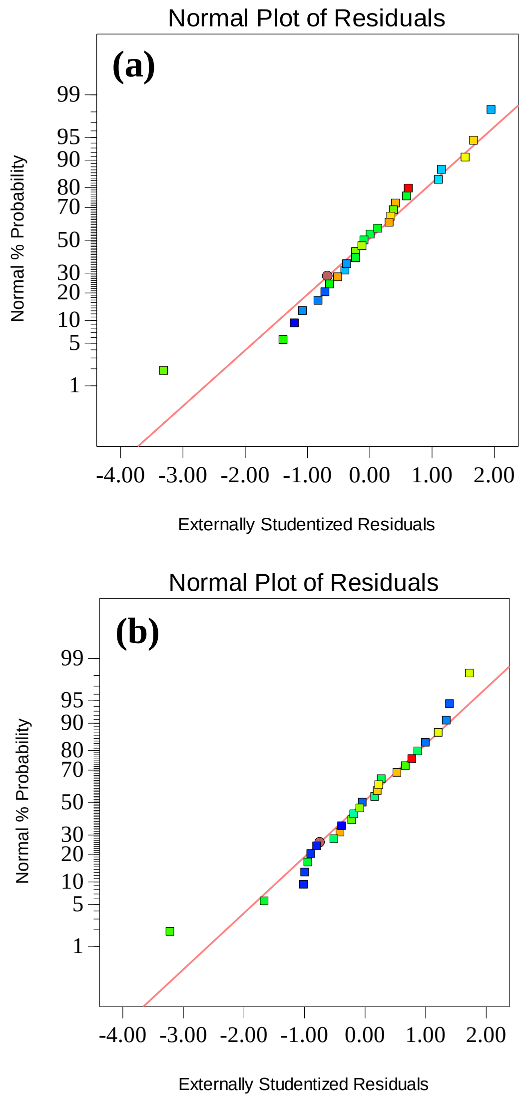


Fig. 5. Normal probability plot for surface roughness during dry (a) and wet condition (b)

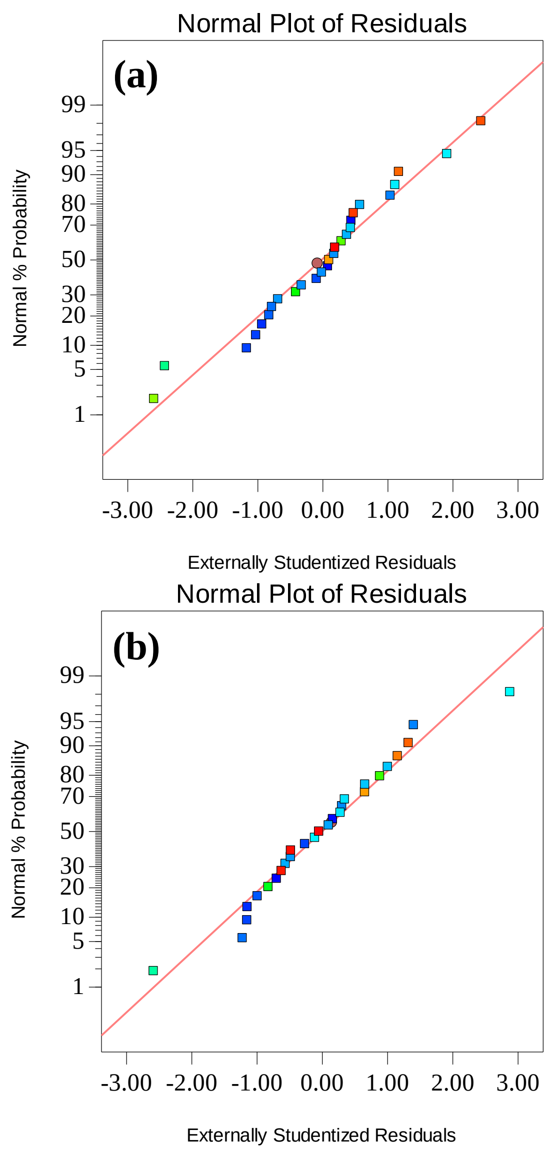


Fig. 6. Normal probability plot for tool tip temperature during dry (a) and wet condition (b)

3.4 Regression Analysis

The regression analysis was achieved to obtain a correlation between the input and output response parameters. These models are developed by ***Design Expert 10*** software. The relationship between input cutting parameters and output responses of performance measures was modeled by the second order quadratic equation. The regression equation is very useful to obtain predicted values, and this will be compared with experiment result [18, 22, 23]. The significance of the developed mathematical model has been tested through the ANOVA as well as the coefficient of determination R^2 value and these R^2 value should be near 1 or 100% then obtained model are adequate. The following regression equation for F_z, R_a & T with corresponding experimental versus predicted plots as shown from Figure 7 to Figure 8. It was observed that which gives satisfactory results with actual values. It was observed that the regression equation predicted the values of much closer to the actual values.

(a) Regression equation for Cutting force using coated inserts during dry and wet condition

$F_z\ Dry = 267 - (1664\times ap) - (0.289\times Vc) - (211\times f) - (0.847\times ap\times Vc) + (3571\times ap\times f) + (1.089\times Vc\times f) + (6285\times ap\times ap) + (0.000238\times Vc\times Vc) - (3454\times f\times f)$
R^2=87.32%

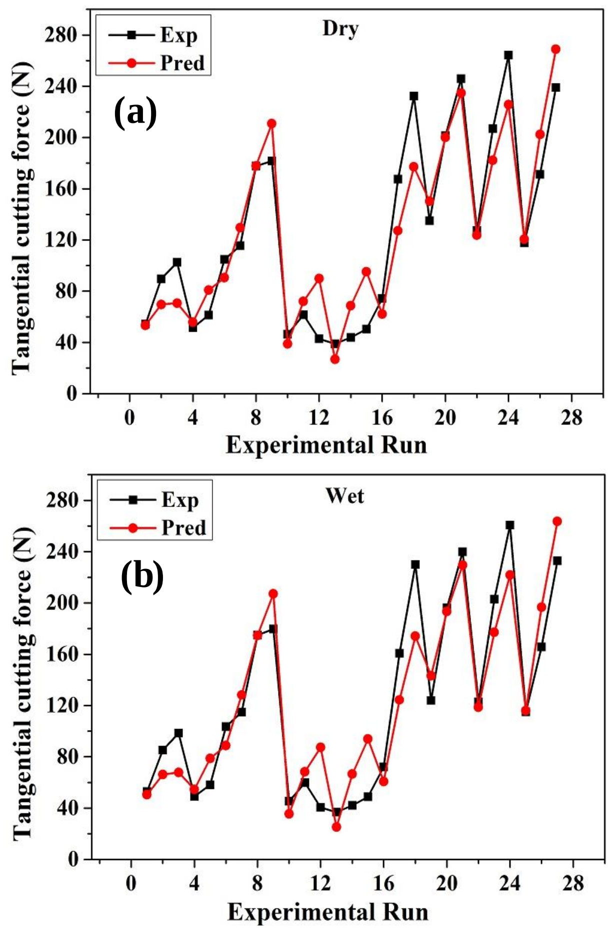


Fig. 7. Experimental v/s predicted values of cutting force during dry (a) and wet condition (b)

$F_z\ Wet = 249 - (1633\times ap) - (0.254\times Vc) - (251\times f) - (0.842\times ap\times Vc) + (3664\times ap\times f) + (1.047\times Vc\times f) + (6136\times ap\times ap) + (0.000221\times Vc\times Vc) - (3144\times f\times f)$
R^2=87.05%

(b) Regression equation for Surface roughness using coated inserts during dry and wet condition

$R_a\ Dry = -1.20 + (2.21\times ap) + (0.00761\times Vc) + (37.3\times f) - (0.00753\times ap\times Vc) + (18.4\times ap\times f) - (0.02527\times Vc\times f) + (9.5\times ap\times ap) - (0.000004\times Vc\times Vc) - (29.4\times f\times f)$
R^2=96.81%

$R_a\ Wet = -1.21 + (1.66\times ap) + (0.00635\times Vc) + (41.9\times f) - (0.00625\times ap\times Vc) + (10.5\times ap\times f) - (0.02861\times Vc\times f) + (10.9\times ap\times ap) - (0.000003\times Vc\times Vc) - (33.4\times f\times f)$
R^2=97.22%

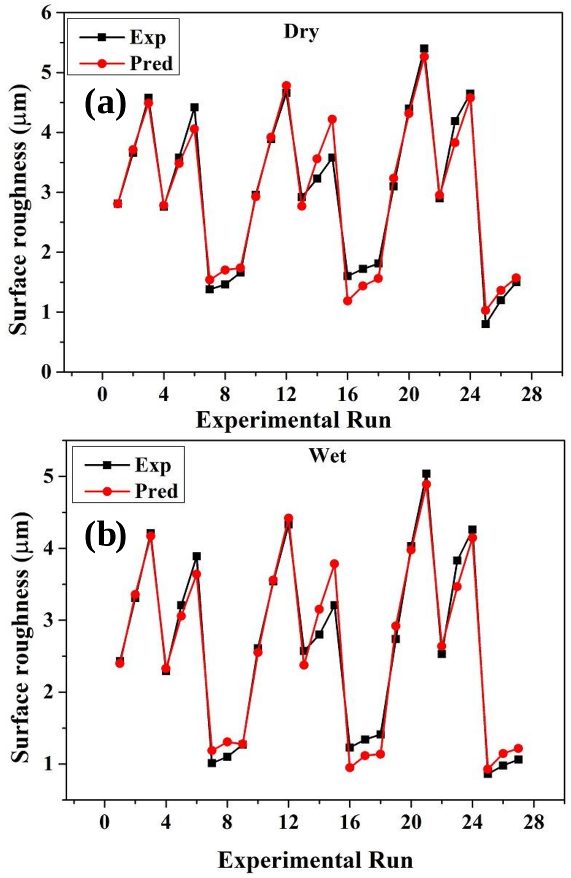
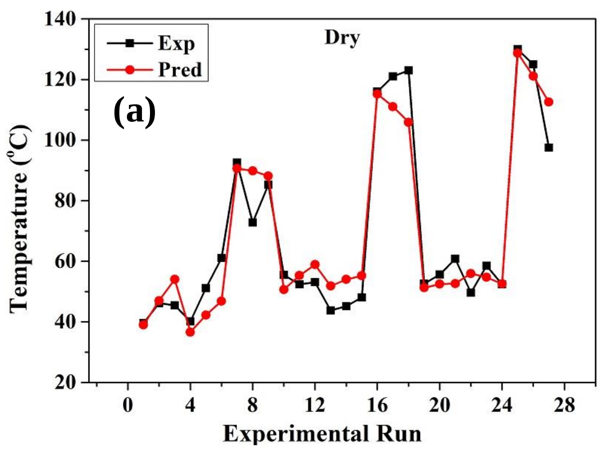


Fig. 8. Experimental v/s predicted values of surface during dry (a) and wet condition (b)

(b) Regression equation for tool tip temperature using coated inserts during dry and wet condition

T Dry = 123.0 + (188× ap) - (0.323× Vc) + (461× f) + (0.2065× ap×Vc) - (727 ×ap×f) - (0.298× Vc×f) - (554× ap×ap) + (0.000213 ×Vc×Vc) - (224 ×f×f)
R^2=92.65%

T Wet = 151.0 -(24× ap) - (0.3531× Vc) + (90× f) +(0.3300× ap×Vc) - (102× ap×f) -(0.128× Vc×f) - (363× ap×ap) +(0.000210 ×Vc×Vc) + (560× f×f)
R^2=95.53%



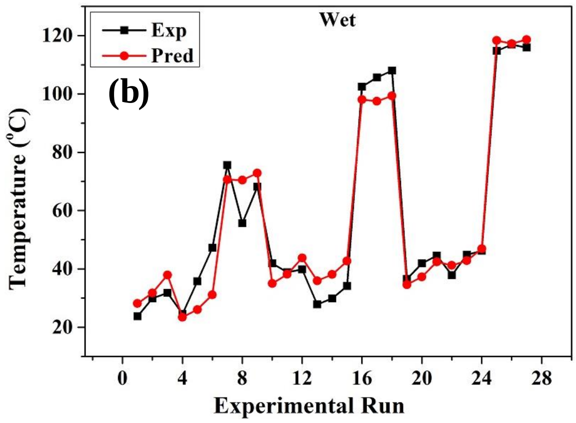


Fig. 9. Experimental v/s predicted values of tool tip temperature during dry (a) and wet condition (b)

3.5 Optimum condition

From the main effect plot optimum conditions are obtained for coated tool insert during dry and wet condition and these are summaries in Table 12 and Table 13.

Table 12. Optimum condition during dry condition

Dry	a_p	V_c	f
Fz	0.2	796	0.046
Ra	0.1	1250	0.046
T	0.1	796	0.046

Table 13. Optimum condition during wet condition

Wet	a_p	V_c	f
Fz	0.2	796	0.046
Ra	0.1	1250	0.046
T	0.1	796	0.046

3.6 Confirmation Test

Confirmation test have been conducted to validate the regression model, cutting condition are chosen near the optimum condition and availability of cutting speed (V_c) and feed rate (f) in the lathe machine, experiments are carried out for selected cutting condition. Results reveal that percentage of error is not cross 5% based on confirmation test so the obtained regression model is adequate. Table 14 and Table 15 depicts confirmation test for dry and wet condition respectively.

Table 14. Confirmation test during dry condition

	a_p	V_c	f	Exp	Pred	% Error
Fz	0.2	572	0.1	78.23	79.34	1.39
Ra	0.1	398	0.117	4.09	4.21	2.89
T	0.3	384	0.16	73.19	75.29	2.8

Table 15. Confirmation test during wet condition

	a_p	V_c	f	Exp	Pred	% Error
Fz	0.2	572	0.1	74.19	75.16	1.29
Ra	0.1	398	0.117	3.95	4.1	3.75
T	0.3	384	0.16	58.63	59.75	1.87

4. CONCLUSIONS

The present work indicates that comparative studies on EN47 spring steel with coated cutting tool insert during dry and wet condition. Experiments are conducted based on design of experiment using full factorial design L_{27} orthogonal array. From experimental work some of the conclusions are drawn:
1) Cutting force influenced by f, V_c and a_p, surface roughness influenced by V_c and f and tool tip temperature influenced by V_c and a_p this is confirmed by ANOVA, main effect plot.
2) Comparison study between dry and wet condition is studied and result reveals that under wet condition surface roughness and tool tip temperature is decreased by 22.59% and 21.29% respectively. Less difference was observed in cutting force during dry and wet machining.
3) From normal probability plots, the model has been investigated by residuals analysis, wherein the residuals are closely fallen on the straight line as it confirmed by normal probability plots.
4) Regression analysis was done on the data obtained from the experimental runs to obtain equations for F_z, R_a and T. It was observed that which gives satisfactory results with actual values. It was observed that regression equation predicted values with least error.
5) From confirmation test results, predicted and experimental results are with error percentage not more than 3.75% so confirming the developed models are adequate to predict the output responses.

5. ACKNOWLEDGMENT

Authors would acknowledge to department of mechanical engineering for all the testing facility and support.

6. REFERENCE

1. Gaitonde, V. N., Karnik, S. R., Figueira, L., Paulo Davim J., (2009). *Machinability investigations in hard turning of AISI D2 cold work tool steel with conventional and wiper ceramic inserts*, Int. J. Refract. Met. Hard Mater., **27**(4), 754–763.
2. Abhang, L. B., Hameedullah, M., (2010). *Power prediction model for turning EN-31 steel using response surface methodology,* J. Eng. Sci. Technol. Rev., **3**(1), 116–122.
3. Aruna, M., Dhanalaksmi, V., (2012). D*esign Optimization of Cutting Parameters when Turning Inconel 718 with Cermet Inserts*, World Acad. Sci. Eng. Technol., International Journal of Mechanical and Mechatronics Engineering, **61**(1), pp. 952–955.
4. Mahamani, A., (2014). I*nfluence of Process Parameters on Cutting Force and Surface Roughness During Turning of AA2219-TiB2/ZrB2 In-situ Metal Matrix Composites*, Procedia Mater. Sci., **6**, 1178–1186.
5. Sayeed Ahmed, G. M., Quadri, S. S. H., Mohiuddin, M. S., (2015). O*ptimization of Feed and Radial Force in Turning Process by using Taguchi Design Approach*, Mater. Today Proc., **2**(4–5), 3277–3285.
6. Kosaraju, S., Chandraker, S., (2015). T*aguchi analysis on cutting force and surface roughness in turning MDN350 steel*, Mater. Today Proc., **2**(4–5), 3388–3393.
7. Bensouilah, H., Aouici, H., Meddour, I., Yallese, M. A., Mabrouki, T., Girardin, F., (2016). *Performance of coated and uncoated mixed ceramic tools in hard turning process*, Measurement, **82**, 1–18.
8. Vasu, M., Shivananda, N. H., (2018). *Comparative study of coated and uncoated tool inserts with dry machining of EN47 steel using Taguchi L9 optimization technique*, in AIP Conference Proceedings, **1943**, p. 020063, https://doi.org/10.1063/1.5029639.
9. Vasu, M., Shivananda Nayaka, H., (2018). *Investigation of machinability characteristics on EN47 steel for cutting force and tool wear using optimization technique,* Mater. Res. Express, **5**(6), DOI:10.1088/2053-1591/aac67f.
10. Vasu, M., Nayaka, H. S., (2018). *Comparative study of turning process on EN47 spring steel with different nose radii using statistical technique*, Mater. Today Proc., **5**(9), 16893–16903.
11. Vasu, M., Nayaka, H. S. (2018). *Investigation of Cutting Force Tool Tip Temperature and Surface Roughness during Dry Machining of Spring Steel*. Materials Today: Proceedings, **5**(2), 7141-7149
12. Pawade, R. S., Joshi, S. S., Brahmankar, P. K., Rahman, M., (2007). *An investigation of cutting forces and surface damage in high-speed turning of Inconel 718*, J. Mater. Process. Technol., **192–193**, 139–146.
13. Amini S., Fatemi, M. H., Atefi, R., (2014). *High speed turning of inconel 718 using ceramic and carbide cutting tools*, Arab. J. Sci. Eng., **39**(3), 2323–2330.
14. Aouici, H., Bouchelaghem, H., Yallese, M. A., Elbah, M., Fnides, B., (2014). *Machinability investigation in hard turning of AISI D3 cold work steel with ceramic tool using response surface methodology*, Int. J. Adv. Manuf. Technol., **73**(9–12), 1775–1788.
15. Bouacha, K., Yallese, M. A., Mabrouki, T., Rigal, J. F., (2010). *Statistical analysis of surface roughness and cutting forces using response surface methodology in hard turning of AISI 52100 bearing steel with CBN tool*, Int. J. Refract. Met. Hard Mater., **28**(3), 349–361.
16. Ravi, A. M., Murigendrappa, S. M., Mukunda, P. G., (2014). *Experimental investigation on thermally*

enhanced machining of high-chrome white cast iron and to study its machinability characteristics using Taguchi method and artificial neural network, Int. J. Adv. Manuf. Technol., **72**(9–12), 1439–1454.
17. Siddesh Kumar, N. G., Shiva Shankar, G. S., Basavarajappa, S., Suresh, R., (2017). *Some studies on mechanical and machining characteristics of Al2219/n-B 4 C/MoS 2 nano-hybrid metal matrix composites,* Measurement, **107**, 1–11.
18. Chabbi, A., Yallese, M. A., Nouioua, M., Meddour, I., Mabrouki, T., Girardin, F., (2017). *Modeling and optimization of turning process parameters during the cutting of polymer (POM C) based on RSM*, ANN, and DF methods, Int. J. Adv. Manuf. Technol., **91**(5–8), 2267–2290.
19. Sivaiah, P., Chakradhar, D., (2017). *Machinability studies on 17-4 PH stainless steel under cryogenic cooling environment*, Mater. Manuf. Process., **32**(15), 1775–1788.
20. Sam Paul, P., Varadarajan, A. S., Robinson Gnanadurai, R., (2015). *Study on the influence of fluid application parameters on tool vibration and cutting performance during turning of hardened steel*, Eng. Sci. Technol. an Int. J., **19**(1), 241-253.
21. Chabbi, A., Yallese, M. A., Meddour, I., Nouioua, M., Mabrouki, T., Girardin, F., (2017). *Predictive modeling and multi-response optimization of technological parameters in turning of Polyoxymethylene polymer (POM C) using RSM and desirability function*, Meas. J. Int. Meas. Confed., **95**, 99–115.
22. Hessainia, Z., Belbah, A., Yallese, M. A., Mabrouki, T., Rigal, J. F., (2013). *On the prediction of surface roughness in the hard turning based on cutting parameters and tool vibrations*, Meas. J. Int. Meas. Confed., **46**(5), 1671–1681.
23.Vasu, M., Nayaka, H. S. (2018). *Turning process on EN47 spring steel with different tool nose radii using OFAT approach*. Advances in Modelling and Analysis A (Scopus), 55(2), 43-46.

Received: August 07, 2019 / Accepted: December 15, 2019 / Paper available online: December 20, 2019