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Performance Analysis of Mild Steel (ASTM A36) under Varying Drilling Conditions using Taguchi and ANOVA

By Md. Al Amin, Usama Abdullah Rifat, Md. Habibur Rahman & Md. Golam Kibria
Khulna University of Engineering & Technology

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PERFORMANCEANALYSISOFMILDSTEELASTMA36UNDERVARYINGDRILLINGCONDITIONSUSINGTAGUCHIANDANOVA

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Md. Al Amin [α], Usama Abdullah Rifat [σ], Md. Habibur Rahman [ρ] & Md. Golam Kibria [Ѡ]

Abstract- This study is conducted to analyze the performance of Mild Steel (ASTM A36) using a drill bit (8.25mm &10.25mm high-speed steel) at two different speeds (270 & 630 RPM) under the three conditions (Dry, MQL, and Wet). The Taguchi has been introduced to find out the most influential factors and most of the cases it was drilling conditions. This performance study has been accelerated by using minitab18 software for ANOVA analysis. Thus it gives the clear indication about the effects of RPM, drilling conditions and drill bit size on drilling a particular materials MS (ASTM A36). The conditions and factors have been shown whether it is statistically significant and how much. One conspicuous thing that the interaction between conditions and factors also have the significant effect. The wet cooling condition has shown the better performance on surface roughness for all conditions and drill bit size. The drilling under wet cooling and MQL conditions have almost the same results but it varies in the case of the dry condition. Low RPM is found to be statistically significant than it is for high RPM. The regression line equation can bring the remarkable significance of further drilling Mild Steel at any drilling conditions.

Keywords: MQL, drilling conditions, MS (ASTM A36), drill bit size, RPM, taguchi, anova.

I. Introduction & Literature Review

Drilling is the operation of cutting a hole of circular cross-section in solid materials using a drill bit. The drill bit is usually a rotary cutting tool, often multipoint. The drill bit is pressed against the workpiece and rotated at rates from hundreds to thousands of revolutions per minute. A drilling machine comes in many shapes and sizes, from small hand-held power drills to bench mounted and finally floor-mounted models. They can perform operations other than drilling, such as countersinking, counterboring, ream, and tap large or small holes (Eskicioglu & Davies, 1983; Kibbe, White, Meyer, Curran, & Stenerson, 2014; Lemelson, 1967).

Anderson & Whitcomb (2016) defined Minimum Quantity Lubrication (MQL) as the use of cutting fluids of only a minute amount-typically of a flow rate of 50-500 ml/hour-which is about three to four orders of magnitude lower than the amount commonly used in flood cooling. The concept of Minimum Quantity Lubrication (MQL), sometimes referred to as near dry lubrication 'or micro lubrication (Asad, Girardin, Mabrouki & Rigal, 2008).

A large amount of heat is generated in dry machining because of rubbing between the cutting tool and workpiece. The application of cutting fluid during machining operation reduces cutting zone temperature and increase tool life yet it causes skin and lung disease to the operators and air pollution (Ezugwu & Lai, 1995; Beaubien & Cattaneo, 1964).

Ahsan, Kibria, Ahmed, Islam & Hossain (2010) found that MQL generally uses vegetable oil or ester oil as the cutting fluid. These high- performing oils have excellent lubrication and natural dissolving properties. This result avoids pollution of the environment and related problems of health and safety, and drastically reduces lubricant costs (Khan, Mithu & Dhar, 2009), although it may cause problems of corrosion (Kirkaldy & Young, 1987). Furthermore, they are environmentally friendly (Khan, Mithu & Dhar, 2009). In our study, Diod sol-M is used as a lubricant. According to a survey conducted by the European Automobile Industry, the cost incurred on lubricants comprises nearly 20% of the total manufacturing cost. The cost of the cutting tool is only 7.5% of the total cost (Brockhoff & Walter, 1998).

Braga, Diniz, Miranda, & Coppini (2002) compared the performances of the uncoated and diamond coated carbide drills, using minimal lubrication (10 ml/h of oil in a flow of compressed air) and abundant soluble oil as a refrigerant/lubricant in the drilling of aluminum-silicon alloys (A356).

In the experiments cutting speeds of 10–50 m/min and feed of 0.1–0.2 mm were used. The lubrication was applied either with an external nozzle or internally through the drill. It was concluded that the measured temperature with the application of MQL internally through the tool was 50% smaller than those obtained with MQL applied with an external nozzle. When MQL was applied with an external nozzle the greatest temperature was measured in a piece drilled with an uncoated drill. For different coatings, there was no significant variation in temperature (Zeilmann & Weingaertner, 2006). A study was conducted at Georgia Institute of Technology to compare the mechanical performance of minimum quantity lubrication over completely dry lubrication for the turning of hardened

Author α σ ρ Ѡ: Department of Industrial Engineering and Management, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. e-mail: alaminkuet01@gmail.com

bearing-grade steel materials with low content CBN cutters (Liang & Ronan, 2003).

A series of MQL drilling tests were conducted to determine if a high penetration rate could be achieved under oil delivery rate was 50 ml/hr, Air pressure for all tests was 4.96 bars, and air consumption was approx. 31 l/min. It was concluded that MQL process costs were approximately 10% lower than the traditional machining process. Dry chips were produced and could have been sold to a recycling facility without additional processing. Air quality for MQL was better than conventional machining, with a significant reduction in aerosol particle concentration (Filipovic & Stephenson, 2006). Taguchi method analyzes the influence of parameter variation on response characteristics. Thereby, and an optimal result can be obtained from the sensitivity analysis respect to parameter variation. However, Taguchi method has shown some defects in dealing with the problems of multiple performance characteristics (Bement, 1989; Roy, 2001; Berginc, Kampus & Sustarsic, 2006; Kopač, Bahor & Sokovć, 2002; Li & Hong, 2005; Ming -der & Yih-fong, 2004; Grzesik, Rech, & Wanat, 2006). Further, design optimization for quality was carried out and signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were employed using experimental results to confirm the effectiveness of this approach (Yang & Tarng 1998; Islam et al., 2015). The main objective of this paper is to analyze the performance of mild steel (ASTM A36) under varying drilling conditions. The rest of the paper is organized as follows: section 2 Experimental setup with working principle section 3 Data Analysis and Interpretation section 4 ANOVA Analysis section 5 Graphical Analysis section 6 Findings and section 7 Conclusion.

II. Experimental Setup With Working Principle

In this study lubricant and the air is mixed by MQL setup which is based on spray gun concept. The two separate hollow pipes carry lubricant and air which mixed in mixing chamber just before the tip of the nozzle. The lubricant flow is controlled by the knob. In order to have contentious mist, constant pressure is assured by the pressure gauge reading because the change in pressure may vary the quantity of the lubricant coming out of the nozzle. The developed MQL system consists of four major parts (a) compressor (b) lubricating Oil reservoir (c) Mixing chamber (d) Nozzle The lubricating agent needs to be supplied at high pressure and impinged at high speed through the nozzle at the cutting zone under MQL condition. Considering the requirements for the present work and uninterrupted supply of MQL at constant pressure, an MQL delivery system has been designed and fabricated. The thin but high-velocity stream of MQL was projected in such a direction so that the coolant could reach as close to the chip-tool and the work-tool interfaces as possible.

(a) MQL set up (b) Operation performing on MQL

Figure 1: Photographic view of MQL set up and an operation performing on MQL.

III. Data Analysis And Interpretation

The data obtained from the experimental investigation are analyzed with two statistical tools Taguchi and ANOVA. All collected data were recorded using Microsoft Excel and transferred to Minitab 17 statistical software for the ANOVA analysis. Before ANOVA analysis the normality test has been performed to check whether the data is normal & fit for the ANOVA analysis.

Taguchi design under varying conditions are shown in table 3.1 below:

Table 3.1: Taguchi Design

Drilling conditions	RPM	Drill bit: 8.25mm			Drill bit: 10.25mm		
		Feed (mm/rev)	Roughness (Ra), mm	S/N Ratio	Feed (mm/rev)	Roughness (Ra), mm	S/N Ratio
Dry	270	0.158	3.835	-11.67	0.123	3.341	-10.477
	270	0.158	3.496	-10.87	0.123	3.209	-10.127
	270	0.158	3.380	-10.57	0.123	3.422	-10.685
	270	0.080	3.896	-11.81	0.060	3.545	-10.992
	270	0.080	3.873	-11.76	0.060	3.007	-9.562
	270	0.080	3.962	-11.95	0.060	3.812	-11.623
	630	0.158	3.243	-10.21	0.123	3.455	-10.768
	630	0.158	3.468	-10.80	0.123	3.168	-10.015
	630	0.158	3.378	-10.57	0.123	3.393	-10.611
	630	0.080	3.541	-10.98	0.060	3.398	-10.624
	630	0.080	3.969	-11.97	0.060	3.764	-11.512
	630	0.080	3.714	-11.39	0.060	3.731	-11.436
MQL	270	0.158	2.865	-9.14	0.123	2.898	-9.241
	270	0.158	2.817	-9.00	0.123	2.770	-8.849
	270	0.158	3.596	-11.11	0.123	2.587	-8.255
	270	0.080	3.129	-9.90	0.060	2.728	-8.716
	270	0.080	2.574	-8.21	0.060	2.785	-8.896
	270	0.080	2.945	-9.38	0.060	2.794	-8.924
	630	0.158	2.914	-9.28	0.123	2.904	-9.259
	630	0.158	3.292	-10.34	0.123	2.864	-9.139
	630	0.158	2.695	-8.61	0.123	3.168	-10.015
	630	0.080	2.909	-9.27	0.060	2.806	-8.961
	630	0.080	3.436	-10.49	0.060	2.899	-9.244
	630	0.080	3.354	-10.51	0.060	2.803	-8.952
Wet	270	0.158	2.963	-9.43	0.123	2.898	-9.241
	270	0.158	3.470	-10.80	0.123	2.870	-9.157
	270	0.158	2.483	-7.89	0.123	2.611	-8.336
	270	0.080	2.988	-9.50	0.060	2.440	-7.747
	270	0.080	2.999	-9.53	0.060	2.721	-8.694
	270	0.080	2.885	-9.20	0.060	2.868	-9.151
	630	0.158	3.409	-10.65	0.123	2.758	-8.811
	630	0.158	2.901	-9.25	0.123	3.113	-9.863
	630	0.158	3.042	-9.66	0.123	2.982	-9.490
	630	0.080	2.930	-9.33	0.060	2.967	-9.446
	630	0.080	2.895	-9.23	0.060	2.602	-8.306
	630	0.080	3.358	-10.52	0.060	3.137	-9.930

Response table for surface roughness with 8.25mm drill bit is shown in table 3.2 below:

Table 3.2: Response table for surface roughness

Level	S/N response (Drill bit: 8.25mm)			Mean response (Drill bit: 8.25mm)		
	Condition's (Dry, MQL ,Wet)	RPM (270 & 630 rpm)	Feed (mm/rev)	Condition's (Dry, MQL ,Wet)	RPM (270 & 630 rpm)	Feed (mm/rev)
1	-11.212	-10.095	-9.991	3.646	3.230	3.180
2	-9.603	-10.170	-10.273	3.043	3.247	3.297
3	-9.582			3.026		
Delta	1.630	0.075	0.282	0.62	0.017	0.117
Rank	1	3	2	1	3	2

The response table 3.2 for surface roughness of the MS (ASTM A36) gives the clear indication that drilling conditions is the most influential factors then RPM and Feed respectively. The Wet condition, high feed and low RPM is better for surface roughness. The order of influential factors both for S/N response and mean response are same.

Response table for surface roughness with 10.25mm drill bit is shown in table 3.3 below:

Table 3.3: Response table for surface roughness

Level	S/N response (Drill bit: 10.25mm)			Mean response (Drill bit: 10.25mm)		
	Condition's (Dry, MQL ,Wet)	RPM (270 & 630 rpm)	Feed (mm/rev)	Condition's (Dry, MQL ,Wet)	RPM (270 & 630 rpm)	Feed (mm/rev)
1	-10.702	-9.370	-9.991	3.437	2.961	3.022
2	-9.037	-9.799	-10.273	2.833	3.106	3.044
3	-9.014			2.830		
Delta	1.688	0.429	2.313	0.607	0.145	0.022
Rank	2	3	1	1	2	3

For the variation in drill bit diameter the S/N response table 3.3 has shown that the feed is the most influential factor rather than drilling conditions which ranked in positions 1. Still, now the Wet condition is better for surface roughness. The mean response indicates that the drilling conditions are the most influential factors. The surface roughness is better at Wet, MQL, dry respectively. Here, 270 rpm is better for surface roughness rather than 630 rpm but their values almost same. The order of influential factors here is drilling conditions, RPM, and Feed respectively.

IV. Anova Analysis

a) *ANOVA Assumptions*

1. Individual differences and errors of measurement are normally distributed within each group.
2. Size of the variance and distribution of individual differences and random errors are identical in each group.
3. Individual differences and errors of measurement are independent of the group to group.

b) *ANOVA Hypothesis*

1. Null Hypothesis: There is no significant difference between the responses obtained by varying the individual input variables.
2. Alternate Hypothesis: There is a significant difference between the responses obtained by varying the individual input variables.

c) *ANOVA Results*

For ease of use, the following factors have been coded as below when used in Minitab.

Dry: Coded as 11

MQL: Coded as 12

Wet: Coded as 13

270 RPM: Coded as 1

630 RPM: Coded as 2

The surface roughness analysis of variance results for drilling mild steel with 8.25 mm drill bit is shown in the following table 4.1

Table 4.1: ANOVA results for surface roughness

General Linear Model: Ra versus Speed, Condition

Analysis of Variance

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Speed	1	0.0163	0.01630	0.24	0.623
Condition	2	15.3869	7.69346	114.42	0.000
Speed*Condition	2	0.1135	0.05675	0.84	0.432
Error	174	11.6990	0.06724		
Total	179	27.2158			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.259299	57.01%	55.78%	54.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.1936	0.0193	165.24	0.000	
Speed					
1	-0.0095	0.0193	-0.49	0.623	1.00
Condition					
11	0.4083	0.0273	14.94	0.000	1.33
12	-0.1474	0.0273	-5.39	0.000	1.33
Speed*Condition					
1 11	0.0110	0.0273	0.40	0.687	1.33
1 12	-0.0347	0.0273	-1.27	0.205	1.33

Regression Equation

Ra = 3.1936 - 0.0095 Speed_1 + 0.0095 Speed_2 + 0.4083 Condition_11 - 0.1474 Condition_12 - 0.2608 Condition_13 + 0.0110 Speed*Condition_1 11 - 0.0347 Speed*Condition_1 12 + 0.0237 Speed*Condition_1 13 - 0.0110 Speed*Condition_2 11 + 0.0347 Speed*Condition_2 12 - 0.0237 Speed*Condition_2 13

Fits and Diagnostics for Unusual Observations

Obs.	Ra	Fit	Resid.	Std. Resid.	
21	3.0340	3.6034	-0.5694	-2.23	R
30	2.9780	3.6034	-0.6254	-2.45	R
33	3.5960	3.0019	0.5941	2.33	R
62	3.4700	2.9470	0.5230	2.05	R
150	3.6720	3.0904	0.5816	2.28	R
179	3.5330	2.9186	0.6144	2.41	R

R Large residual

Table 4.1 shows the effect of cutting condition, cutting speed and their interaction on surface roughness. For speed the null hypothesis is accepted, that is, there is no statistically significant difference in the mean between the different groups of independent variables. But for the condition the null hypothesis is rejected, that is, there is a statistically significant difference in the mean between the different groups of independent variables. The interaction effect is not statistically significant. That is, the effect of cooling condition on surface roughness is not dependent on cutting speed (and vice versa).

The surface roughness analysis of variance results for drilling mild steel with 10.25 mm drill bit is shown in the following table 4.2

Table 4.2: ANOVA for surface roughness

General Linear Model: Ra versus Speed, Condition

Analysis of Variance

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Speed	1	1.6182	1.61824	44.59	0.000
Condition	2	19.4964	9.74819	268.61	0.000
Speed*Condition	2	0.1675	0.08374	2.31	0.103
Error	174	6.3147	0.03629		
Total	179	27.5968			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.190503	77.12%	76.46%	75.51%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.0778	0.0142	216.76	0.000	
Speed					
1	-0.0948	0.0142	-6.68	0.000	1.00
Condition					
11	0.4598	0.0201	22.90	0.000	1.33
12	-0.1676	0.0201	-8.34	0.000	1.33
Speed*Condition					
1 11	0.0426	0.0201	2.12	0.035	1.33
1 12	-0.0273	0.0201	-1.36	0.176	1.33

Regression Equation

Ra = 3.0778 - 0.0948 Speed_1 + 0.0948 Speed_2 + 0.4598 Condition_11 - 0.1676 Condition_12 - 0.2923 Condition_13 + 0.0426 Speed*Condition_1 11 - 0.0273 Speed*Condition_1 12 - 0.0153 Speed*Condition_1 13 - 0.0426 Speed*Condition_2 11 + 0.0273 Speed*Condition_2 12 + 0.0153 Speed*Condition_2 13

Fits and Diagnostics for Unusual Observations

Obs.	Ra	Fit	Resid	Std Resid	
5	3.0070	3.4854	-0.4784	-2.55	R
21	3.9090	3.4854	0.4236	2.26	R
23	2.9400	3.4854	-0.5454	-2.91	R
27	3.0900	3.4854	-0.3954	-2.11	R
92	3.1680	3.5898	-0.4218	-2.25	R
112	3.1950	3.5898	-0.3948	-2.11	R
120	3.1150	3.5898	-0.4748	-2.54	R

R Large residual

Table 4.2 shows the effect of cutting condition, cutting speed and their interaction on surface roughness. For the speed and conditions the null hypothesis is rejected, that is, there is a statistically significant difference in the mean between the different groups of independent variables. The interaction effect is not statistically significant. That is, the effect of cooling condition on surface roughness is not dependent on cutting speed (and vice versa).

V. Graphical Analysis

The performance of MS (ASTM A36) is highlighted in a graphical manner to aid the analysis. The correlation analysis for surface roughness has been shown with respect to the no. of holes drilled under varying drilling conditions. The graphical results support as the results found in both Taguchi and ANOVA.

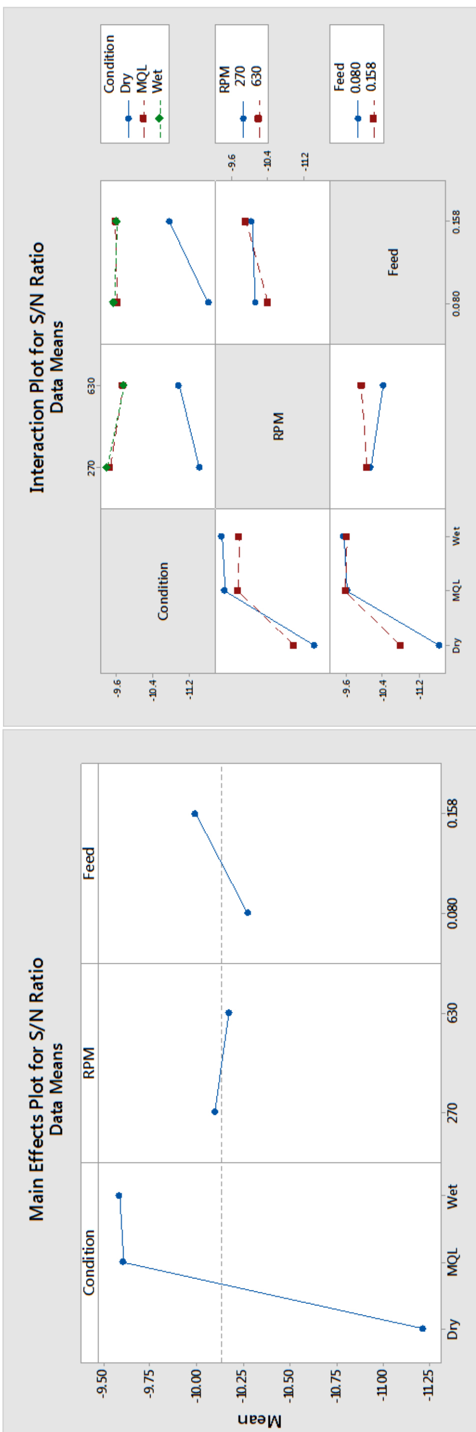

Fig. 5.1: Main effects and Interaction effects plot for S/N Ratio

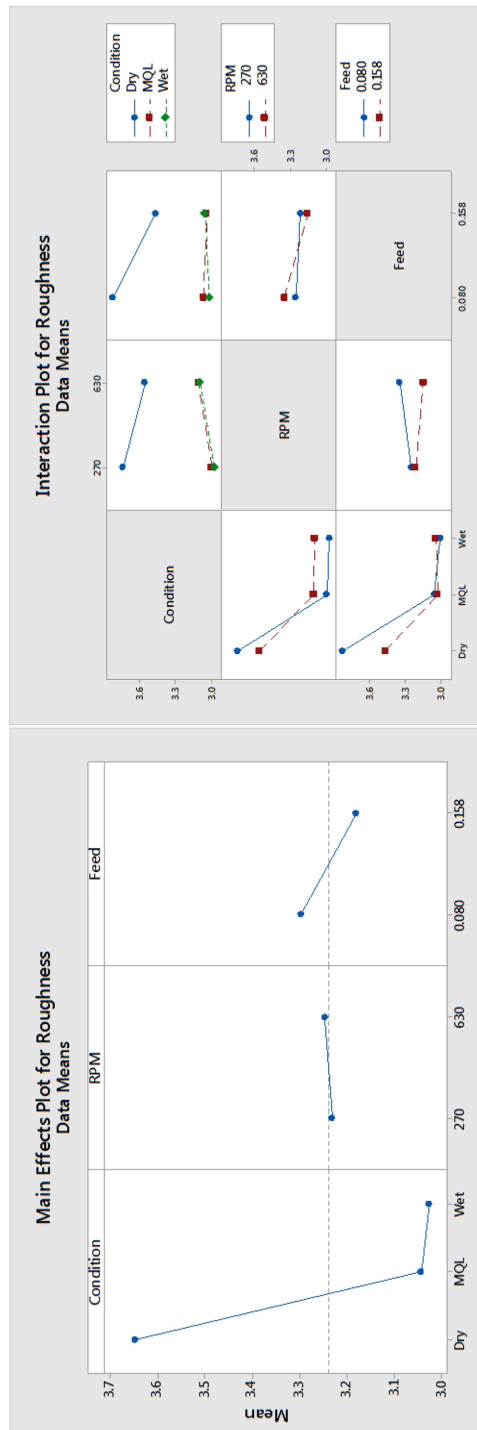

Fig. 5.2: Main effects and Interaction effects plot for surface roughness

From Fig.5.1 Main effects and Interaction effects plot for S/N Ratio, it has been seen that the in the wet condition the roughness is better than the MQL and dry respectively. Here the drilling conditions are the most influential factors than RPM and Feed. Also, the high feed and low RPM is better for surface roughness. Performance measure on MQL and wet machining have almost the same results.

From Fig.5.2 Main effects and Interaction effects plot for surface roughness, it has been noticed that For 8.25 mm drill bit, Surface roughness varies in the range of 3.034 to 3.962 mm for dry machining. Surface roughness varies in the range of 2.565 to 3.596 mm for MQL machining. Surface roughness varies in the range of 2.458 to 3.47 mm for flood machining. It can be seen from the graph that surface roughness for MQL machining is closer to flood machining than dry machining. For 10.25 mm drill bit, Surface roughness varies in the range of 2.940 to 3.909 um for dry machining. Surface roughness varies in the range of 2.552 to 3.021 mm for MQL machining. Surface roughness varies in the range of 2.425 to 2.898 mm for flood machining. It can be seen from the graph that surface roughness for MQL machining is closer to flood machining than dry machining.

VI. Findings

Taguchi, ANOVA, and graphical analysis results under varying drilling conditions, Drill bit size and RPM are:

a) Drilling conditions are the most influential factor
b) Wet machining condition is better for surface roughness
c) Low rpm (270 rpm) is better for surface roughness
d) For 8.25mm drill bit, the speed, conditions, and interaction effect are not statistically significant that is there is no statistically significant difference in the mean between the different groups of independent variables.
e) For 10.25mm drill bit, the speed and conditions have statistical significance but interaction effect is not statistically significant.
f) Performance measure on MQL and wet machining have almost the same results.

VII. Conclusion

Performance analysis of Mild Steel (ASTM A36) at varying drilling conditions, drill bit size and RPM is very useful research work in the field of manufacturing. Statistical tools Taguchi, ANOVA are used to analyze the performance of surface roughness under varying conditions and factors. Drilling conditions are found to be most influential factors rather than drill bit size and RPM. Wet machining conditions and low RPM is better for surface roughness. This research work will help to further analysis of drilling Mild Steel (ASTM A36) and its performance measure. The obtained results can also be the asset in the respective field. It can easily be derived from the regression line equations what would be the performance for any drilling conditions, drill bit size, and RPM in the next successive operation.

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