

# Investigation on Influence of Speed, Feed and DOC on Surface Roughness in Turning of EN-24 and EN-31 under Dry and Wet Conditions

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**ABSTRACT:** The objective of this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a suitable mathematical model. Such an understanding can provide insight into the problems of controlling the finish of machined surfaces when the process parameters are adjusted to obtain a certain responses like surface finish and power consumption. Also, the demand for high quality and fully automated production focuses attention on the surface condition of the product, especially the roughness of the machined surface, because of its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish. Also, the quality of the machined surface is useful in diagnosing the stability of the machining process, power consumption, MRR, progressive tool wear, cutting tool chatter, etc.

**KEYWORDS:** Orthogonal Array (OA), Taguchi, Regression, Surface roughness.

## I. INTRODUCTION

The main objective of this study is to propose a mathematical model which can predict the surface roughness of EN-24 and EN-31 under lubricated (dry) and unlubricated (wet) machining conditions. There are numerous ways to propose a mathematical model in design of experiments like Response surface methodology, Taguchi Method, Full Factorial design, Fractional factorial design. Here, Taguchi Method is used because it greatly reduces the number of observations and thus saves time and effort. Design of experiments (DOE) is one of the many problem-solving quality tools that can be used for various investigations such as finding the significant factors in a process, the effect of each factor has on the outcome, the variance in the process, troubleshooting the machine problems, screening the parameters, and modelling the processes. By using strategically designed and statistically performed experiments, it is possible to study the effect of several variables at one time, and to study inter-relationships and interactions. DOE is a tool to develop an experimentation strategy that maximizes learning using a minimum of resources. Most of the standard experimental designs can be generated once the experimental objective, the number (and nature) of the design variables, the nature of the responses and the economical number of experimental runs have been defined. Generating such a design will provide the user with the list of all experiments to be performed in order to gather the required information to meet the objectives. With designed experiments there is a better possibility of testing the significance of the effects and the relevance of the whole model. The concept of using OA's to design an experiment was first introduced by Taguchi. The quality of machined components is evaluated by how closely they adhere to set product specifications. Surface finish is central to determining the quality of a work piece. Surface roughness is harder to attain and track than physical dimensions because relatively many factors affect surface roughness [1]. Aslan et al [2] conducted an optimization study by machining a hardened AISI 4140 grade. The experimental parameters chosen were three different cutting speeds, feed rates and depths of cut. The results obtained showed that the surface roughness decreased as the cutting speed increased. In contrast surface roughness increased when the feed rate increased. Yang and Tarn [3] used the Taguchi method for determining optimum cutting parameters. They machined S45C steel work piece with carbide

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cutting tools. The cutting parameters chosen were cutting speed, feed rate and depth of cut. Taguchi's signal– noise ratio and variance analysis were used to determine the effect of the cutting parameters on tool life and surface roughness. They obtained optimum cutting parameters as a result of their studies. Zhang and Chen [4] studied the response variables and signal-to-noise ratios, the determined significant factors were the spindle speed, tool type and peck rate, and the optimal combination of cutting parameters were selected. They verified that the selected optimal combination through Taguchi design achieved the desired surface roughness. Bhattacharya et al [5] investigated the effects of cutting parameters on finish and power consumption by employing Taguchi techniques. Their results showed a significant effect of cutting speed on the surface roughness and power consumption, while the other parameters did not substantially affect the responses. Therefore, optimal cutting parameters were obtained. The most readily controlled factors in a turning operation are feed rate, cutting speed, and depth of cut; each of which may have an effect on surface finish. Spindle speed and depth of cut were found to have differing levels of effect in each study, often playing a stronger role as part of an interaction. The literature survey reveals that traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [6].

This study will utilize the Taguchi Design methodology. This includes selection of factors and levels selecting an appropriate orthogonal array, conducting experimental runs according to the design matrix, analyse the experimental data, determining the optimum combination, conformation and verification of the predicted mathematical model. Paper is organized as follows. Section II describes the Methodology. Section III describes the experimentation and selection of factors, levels and OA's. Section IV focuses on the surface roughness and its measurement. Section V deals elaborately with the results obtained and the mathematical equations used to predict the surface roughness. The main effects plot and the interaction plot are shown in this section. Finally, Section VII presents conclusion.

## II. RELATED WORK AND METHODOLOGY

The literature survey reveals that there is lot of scope for research and exploration in the area of surface roughness. Hence surface roughness is selected as the output parameter. A thorough study on machining and of Taguchi methodology was done and then the input and output parameters were selected. An L9 orthogonal array was selected though the resolution of this orthogonal array is low. The predicted values are in close match with actual values of surface roughness and the results are within 90% confidence level.

The steps mentioned below are followed as guidelines to design and conduct the experiment.

1. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be forces, surface finish, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to minimize surface roughness. The deviation in the performance characteristic from the target value is used to define the loss function for the process.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as speed, feed, depth of cut etc. that can be easily controlled.
3. Create orthogonal arrays for the parameter design indicating the number of columns and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.
6. Conduct conformation and validation experiments to confirm the accuracy of prediction of the proposed regression equations.

## III. EXPERIMENTATION AND SELECTION OF FACTORS, LEVELS AND ORTHOGONAL ARRAY

In this study, work pieces of steel EN-24 and EN-31 of dimensions  $\varnothing 20 \times 70$  mm are used. The machining was carried out on a Kirloskar lathe using single point carbide tool. The experiments were conducted for both dry and lubricated

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(wet) conditions; used petrol engine oil (SAE-40) was utilised as lubricant, sufficient oil was smeared all-round the work piece using a brush. The factors chosen for the experiments are speed (S), feed (f), and depth of cut (d). Level 1 represents low level, Level 2 is the intermediate level and Level 3 is high level; for Level 1 speed, feed and depth of cut are 630(m/min), 0.08(mm/rev) and 0.5(mm) respectively. The values for Level 2 & Level 3 are given in Table 1.

Table. 1. Table shows factors and levels used in the experiment.

S.No	Cutting parameter (Factor)	Level 1	Level 2	Level 3
1	RPM/Cutting velocity, rpm/(m/min)	630/40	840/50	1000/60
2	Feed rate(mm/rev)	0.08	0.11	0.16
3	Depth of Cut (mm)	0.5	1.0	1.5

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which is better and specifically how much better it is. A three level process parameter counts for two degrees of freedom. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for two process parameters. In this study an L9 orthogonal array is used. Each cutting parameter is assigned to a column. The design matrix was generated using Minitab V14. Table 2 represents the coded values of the factors. The values 1, 2 and 3 represents low level, intermediate level and high level. These values correspond to the values given in Table 1.

Table. 2. Table shows design matrix used in the experiment.

S.No	1	2	3	4	5	6	7	8	9
Speed	1	1	1	2	2	2	3	3	3
Feed	1	2	3	1	2	3	1	2	3
Depth of Cut	1	2	3	2	3	1	3	1	2

## IV. MACHINING PERFORMANCE MEASURES

Surface roughness is used such as a measure of machining performance (Ra). Taylor/Hobson, Surtronic 3+ measures the surface irregularities due to roughness and is made unresponsive to more widely spaced irregularities caused by waviness or curvature. The average roughness is measured with a sampling length of 2.5 mm and evaluation length of 0.8 mm. The work piece was divided into 6 equal parts and the readings were observed at 24 locations i.e. 12 readings each on dry and lubricated part on each work piece

## V. EXPERIMENTAL RESULTS

The experiments have been performed on EN-24 and EN-31 materials in accordance with the design matrix obtained earlier. The main effects and the Interaction plot have been plotted using Minitab V14. The graphical comparison of surface roughness for both the materials under dry and lubricated condition is done using MS Excel. Table 3 shows the tangential force  $F(\tan)$ , feed force  $F(\text{feed})$ , and radial force  $F(\text{rad})$ , resultant of the forces, experimental value of surface roughness  $Ra(\text{expt})$  and the predicted value of surface roughness  $Ra(\text{prdt})$  for EN-24 under non lubricated conditions. Surface roughness is measured by Taylor/Hobson, Surtronic 3+ instrument. The experimental values are obtained by using the equations given below.

Table 3. Values of Surface Roughness for EN-24-dry

Speed, <i>S</i>	Feed, <i>f</i>	DOC, <i>d</i>	F(tan) N	F(feed) N	F(rad) N	Resultant	Ra(expt)	Ra(prdt)
630	0.08	0.5	78.480	9.81	68.67	104.7421	1.718	1.877833
630	0.11	1	255.06	78.48	176.58	319.9925	1.6	2.070949
630	0.16	1.5	431.64	127.53	304.11	543.1941	2.105	1.867599
840	0.08	1	284.49	98.1	107.91	319.6916	1.341	1.75714
840	0.11	1.5	353.16	98.1	353.16	508.9868	2	1.114078
840	0.16	0.5	176.58	19.62	255.06	310.8393	1.98	2.407168
1000	0.08	1.5	382.59	78.48	421.83	574.8693	1.195	0.765472
1000	0.11	0.5	196.21	78.48	117.72	241.8916	1.663	1.852022
1000	0.16	1	206.01	39.24	235.44	315.2965	1.615	1.256872

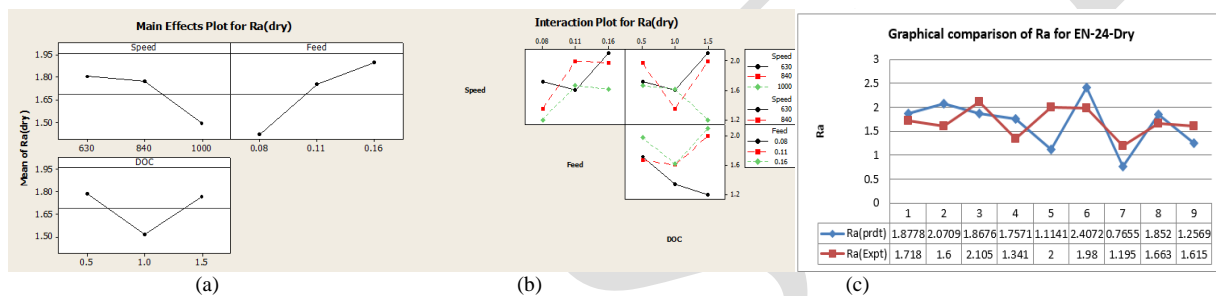


Fig 1. (a) Main Effects plot for Surface roughness for EN-24-Dry (b) Interaction for Surface roughness for EN-24-Dry (c) Graphical comparison of Ra for EN-24-Dry

Fig 1(a) shows that the surface roughness improves as the speed increases, degrades as the feed increases. Surface roughness improves as DOC is increased from 0.5 to 1 mm and then decreases as the DOC is increased. Fig 1 (b) shows the interaction plot of Speed v/s Feed, Speed v/s DOC, and Feed v/s DOC. The lowest surface roughness is obtained at low speed and high DOC as expected. Better surface roughness is obtained at low feed and low DOC. Fig 1(c) shows comparison between the predicted and experimental values of the values of surface roughness. The value of surface roughness for EN-24 under non lubricated (dry) condition is calculated by using the equation given below.

Predicted regression model for surface roughness is

$$Ra_{dry} = 1.354 - 0.000173S + 3.33f + 0.517d + 0.00109Sf - 0.000739Sd + 0.67fd + 0.2620$$

The Table 4 gives the forces, resultant and the values of surface roughness obtained in turning EN-24 under lubricated (wet) condition. The resultant is the square root of the sum of squares of all the forces.

Table 4. Values of Surface Roughness for EN-24-wet

Speed, <i>S</i>	Feed, <i>f</i>	DOC, <i>d</i>	F(tan) N	F(feed) N	F(rad) N	Resultant	Ra(expt)	Ra(prdt)
630	0.08	0.5	78.48	9.81	58.86	98.58928	1.771	1.763315
630	0.11	1	235.44	68.67	68.67	254.6824	1.891	1.97538
630	0.16	1.5	353.16	98.1	294.3	470.0618	2.383	2.402085
840	0.08	1	235.44	78.48	127.53	279.0251	1.585	1.61928
840	0.11	1.5	323.73	107.91	274.68	438.058	1.816	1.741225
840	0.16	0.5	176.58	49.05	206.01	275.7291	1.706	1.6939
1000	0.08	1.5	372.78	78.48	392.4	546.902	1.023	1.06766

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1000	0.11	0.5	186.39	29.43	215.82	286.6804	1.685	1.694375
1000	0.16	1	196.2	29.43	98.1	221.3237	1.743	1.79912

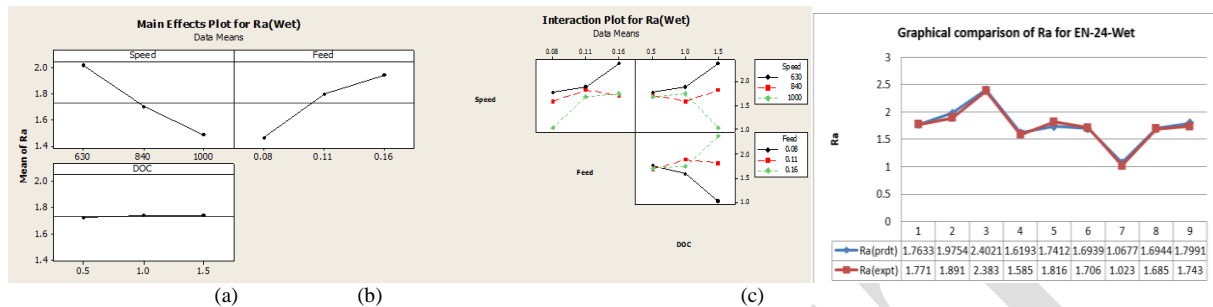


Fig 2. (a) Main Effects plot for Surface roughness for EN-24-wet (b) Interaction for Surface roughness for EN-24-wet (c) Graphical comparison of Ra for EN-24-wet

Fig 2 (a) shows the main effects plot for Surface roughness. Surface roughness improves as the speed increases, degrades as the feed increases. Surface roughness remains fairly constant for all DOC's from 0.5 to 1.5. Fig 2 (b) shows interaction plots for Speed v/s Feed, Speed v/s DOC, and Feed v/s DOC. Better surface roughness is obtained at high speed and low feed, surface roughness increases at low speed and high DOC. At speeds 630 and 1000 and DOC range from 0.5 to 1.0 the unit variation in surface roughness is very less. Better surface roughness is obtained at low feed and low DOC. Fig 3 (c) reveals that the predicted and the experimental values are in close agreement and the model given below can be used to predict the roughness with good accuracy.

Predicted regression model for surface roughness is

$$Ra_{wet} = 2.2906 - 0.000447S - 16.835f + 1.694d + 0.017Sf - 0.002681Sd + 5.619fd + 0.01708$$

Table 5 gives various values of forces and surface roughness obtained during experimentation of EN-31 under non lubricated conditions. The best value 0.655µm is obtained at speed, feed, depth of cut of 1000, 0.11 and 0.5 respectively. The table also shows predicted and experimental values.

Table. 5. Experimental values of Surface Roughness for EN-31-dry

Speed, S	Feed, f	DOC, d	F(tan) N	F(feed) N	F(rad) N	Resultant	Ra(expt)	Ra(prdt)
630	0.08	0.5	196.2	49.05	304.11	365.2167	3.123	3.604366
630	0.11	1	441.45	196.2	353.16	598.41	2.065	2.055202
630	0.16	1.5	588.6	245.25	539.55	835.2914	2.221	2.652702
840	0.08	1	402.21	117.72	637.65	763.0389	0.751	1.377508
840	0.11	1.5	529.74	137.34	470.88	721.952	0.773	1.471006
840	0.16	0.5	372.78	29.43	667.08	764.7397	0.798	1.377996
1000	0.08	1.5	519.93	225.63	402.21	694.9885	0.753	0.9859
1000	0.11	0.5	343.35	49.05	647.46	734.5063	0.655	0.95425
1000	0.16	1	421.83	137.34	461.07	639.8346	1.685	1.9609

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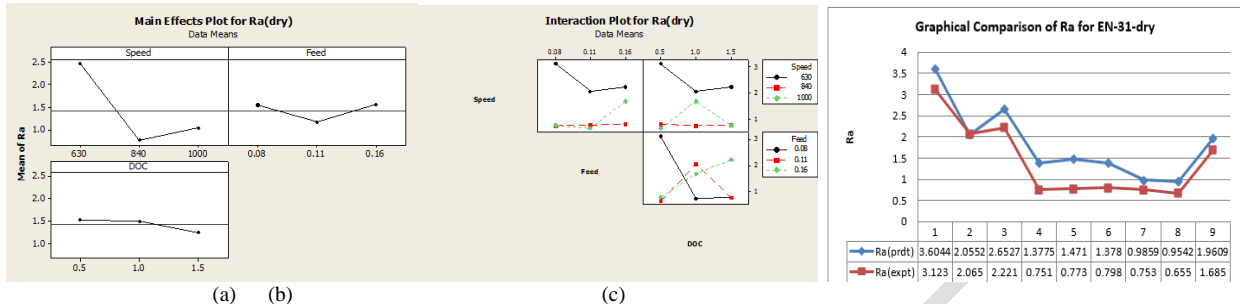


Fig 3. (a) Main Effects plot for Surface roughness for EN-31-dry (b) Interaction for Surface roughness for EN-31-dry (c) Graphical comparison of Ra for EN-31-dry

Fig 3 (a) shows the main effects plot for Surface roughness for EN-31-dry. The surface roughness improves as speed increases from 630 to 840; it decreases for speed range 840 to 1000; similar trend is seen for feed. Surface roughness remained constant for DOC 0.5 to 1.0 and then decreased slightly between ranges 1.0 to 1.5. Fig 3 (b) shows interaction plots for Speed v/s Feed, Speed v/s DOC, and Feed v/s DOC for EN-31-dry. The observations disclose that the unit variation of surface roughness for medium and high speeds is very less for low and medium feed rate. There is drastic variation at low speed. Better surface roughness was obtained at high speed and low feed, least Ra was obtained at low speed and low feed evidently. At low speed it is observed that Ra improves as DOC increases. At medium speed Ra has remained fairly same irrespective of DOC. Lowest Ra is obtained at low feed and low DOC. Fig 3 (c) shows the graphical comparison of Ra for EN-31-dry. The model predicts the value with good accuracy. The equation is given below.

Predicted regression model for surface roughness is

$$Ra_{dry} = 14.128 - 0.010021S - 26.63f - 13.698d - 0.01036Sf + 0.009576Sd + 46.83fd + 0.4015$$

Table 6 gives various values of forces and surface roughness obtained during experimentation of EN-31 under lubricated (wet) conditions. The best value obtained at speed, feed, depth of cut of 1000, 0.08 and 1.5 respectively.

Table.6. Experimental values of Surface Roughness and Power Consumption for EN-31-wet

Speed, S	Feed, f	DOC, d	F(tan) N	F(feed) N	F(rad) N	Resultant	Ra(expt)	Ra(prdt)
630	0.08	0.5	196.2	49.05	235.44	310.3745	2.771	3.537563
630	0.11	1	412.02	107.91	333.54	540.975	1.956	2.090491
630	0.16	1.5	549.36	117.72	510.12	758.8655	1.523	2.188301
840	0.08	1	392.4	117.72	343.35	534.5325	0.746	1.559224
840	0.11	1.5	510.12	98.1	627.84	814.8798	0.598	1.695228
840	0.16	0.5	372.78	78.48	559.17	676.6056	0.616	1.480388
1000	0.08	1.5	529.74	98.1	627.84	827.3035	0.76	1.1951
1000	0.11	0.5	362.97	98.1	451.26	587.3725	0.538	1.1049
1000	0.16	1	372.78	127.53	304.11	497.7065	1.839	2.2894

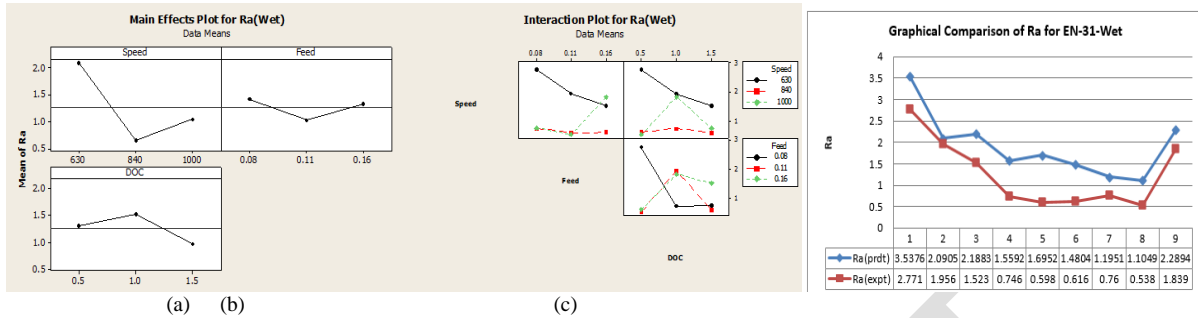


Fig 4. (a) Main Effects plot for Surface roughness for EN-31-wet (b) Interaction for Surface roughness for EN-31-wet (c) Graphical comparison of Ra for EN-31-wet

Fig 4 (a) shows the main effects plot for Surface roughness for EN-31-wet. The surface roughness improves as speed increases from 630 to 840; it decreases for speed range 840 to 1000; similar trend is seen for feed. Surface roughness decreased for DOC 0.5 to 1.0 and then improved between ranges 1.0 to 1.5. Fig 4 (b) shows interaction plots for Speed v/s Feed, Speed v/s DOC, and Feed v/s DOC for EN-31-wet. Better Ra was obtained at high speed and medium feed, least Ra was obtained at low speed and low feed evidently. Speeds of 630 to 840 and feeds range from 0.08 to 0.11 are recommended for better results. Ra for medium speed and low DOC and high speed and high DOC are nearly same. It is recommended to use mentioned feeds and DOC's to get surface roughness. Lowest Ra is obtained at low feed and low DOC. Fig 4(c) shows good agreement between the values of Ra for EN-31-wet. The regression model to predict the surface roughness is given below.

Predicted regression model for surface roughness is

$$Ra_{wet} = 14.949 - 0.012399S - 50.81f - 11.194d + 0.02707Sf + 0.008167Sd + 37fd + 0.6448$$

### VI. COMPARISON OF SURFACE ROUGHNESS FOR EN-24 AND EN-31

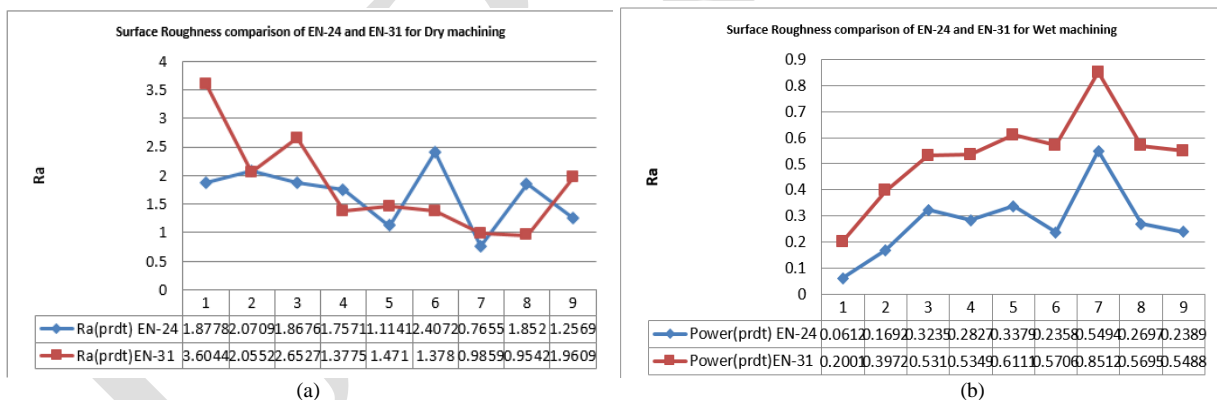


Fig 5.(a) Surface Roughness comparison for EN-24 and EN-31 for dry machining (b) Surface Roughness comparison for EN-24 and EN-31 for wet machining

Fig 5 (a) & (b) show that the results obtained are in 90% confidence level i.e. the predicted and the experimental values are close to each other. The equations mentioned above can be used to predict the surface roughness with good accuracy with the range. This has been confirmed by conducting conformation and validation experiments. The results may or may not yield the correct results beyond the range.

### VII. CONCLUSION

The predicted values and measured values are fairly close which indicates that the developed surface roughness prediction models can be effectively used to predict the surface roughness from the cutting process with 95% confident

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intervals for both case (dry and wet). Discarded engine oil of petrol car can be used as a lubricant as it is observed to improve the surface roughness of materials under consideration. However, its chemical effects on the material have to be studied.

## REFERENCES

- [1] Scott A.Coker, Yung C.Shin, In-process control of surface roughness due to tool wear using a new ultrasonic system, International Journal of Machine Tools and Manufacture, Volume 36, Issue 3, pages 411-422, March 1996.
- [2] E. Aslan, N. Camus\_cu, B. Bingoren, Design optimization of cutting parameters when turning hardened AISI 4140(63 HRC) with Al<sub>2</sub>O<sub>3</sub> + TiCN mixed ceramic tool, Mater. Des. Volume 28, pages 1618–1622, 2007.
- [3] W.H. Yang, Y.S. Tarn, Design optimization of cutting parameters for turning operations based on the Taguchi method, Journal of Materials Processing Technology, Volume 84, pages 122–129, 1998.
- [4] Z. Zhang, J.C. Chen, Surface roughness optimization in a drilling operation using the Taguchi design method, Journal of Material Manufacturing Processes, Volume 24, pages 459–467, 2009.
- [5] A. Bhattacharya, S. Das, P. Majumder, A. Batish, Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA, Production Engineering Resource Development, Volume 3, pages 31–40, 2009.
- [6] E. Bagci, S. Aykut, A study of Taguchi optimization method for identifying optimum surface roughness in CNC face milling of cobalt-based alloy (stellite 6), International Journal of Advanced Manufacturing Technology, Volume 29, pages 940–947, 2006.