Near dry turning on high carbon high chromium steel for improvement of machining performance

[1]P.M.Gaigole, [2]Harshvardhan Uttarwar, [3]Pankaj Saharkar, [4]Ameya Kawtikwar
[1]Assistant Professor, [2,3,4]UG students
[1]Department of Industrial & Production Engineering
[1,2,3,4]Vishwakarma Institute of Technology, Pune, India

ABSTRACT: Gallons of coolant are wasted every day in machining workshops while carrying out different operations with flooded cooling system. This paper presents an experimental study of near-dry turning on High Carbon High Chromium (D3) Steel using Minimum Quantity Lubrication (MQL) applicator, where a small amount of liquid can be used along with the compressed air as lubricant at too-work interface. Vegetable oil- based cutting fluid was used as a lubricant as it is not harmful and improves working environment. The conventional method of lubrication in which the coolant is used in abundance, proves to be costlier and also more problematic in terms of reusing and wastage of the same. However, minimal fluid application provides several benefits in machining. Machining of hardened alloy steel like High Carbon High Chromium Steel is known to be difficult. Attempt has been made to improve the performance characteristics like Material removal rate (MRR) and surface finish (SF) simultaneously in near dry conditions. The objectives of this study includes improving working conditions, reducing the wastage of cooling liquids while maintaining maximum material removal rate and minimum surface roughness. Speed, feed and depth of cut are taken as process variables. L27 orthogonal array is used for experimentation. Analysis of variance (ANOVA) is performed to determine significant process parameters and their contribution in performance characteristics. Optimal parametric setting is obtained to improve MRR and SF. Confirmation experiments are conducted to validate the predicted performance. Study suggests that this method can effectively be used to improve the performance in near dry condition.

***Index Terms* -** High carbon high chromium steel (HCHCR), Minimum quantity lubrication (MQL), L_{27} (3^{13}) orthogonal array, Analysis of variance (ANOVA)

I. INTRODUCTION

MQL consists of a mixture of pressurized air and oil micro-droplets applied directly into the interface between the tool and chips. Minimum quantity lubrication (MQL) has increasingly found its way into the area of metal cutting machining and, in many areas, has already been established as an alternative to conventional wet processing. In contrast to flood lubrication, minimum quantity lubrication uses only a few drops of lubrication (approx. 5 ml to 50 ml per hour) in machining. Today, the enormous cost-saving potential resulting from doing almost entirely without metalworking fluids in machining production is recognized and implemented by many companies, primarily in the automotive industry. While in the early 1990s small applications (sawing, drilling) were done “dry”, today we are able to produce cylinder heads, crankcases, camshafts and numerous other components made of common materials such as steel, cast iron and aluminum using MQL in the framework of highly automated large volume production. With respect to occupational safety, MQL offers numerous advantages over water-mixed metalworking fluids. A major advantage is the substantially better compatibility concerning skin care. Minimum quantity lubrication is a total-loss lubrication method rather than the circulated lubrication method used with emulsions. This means using new, clean lubricants that are fatty-alcohol or ester based. Additives against pollution, e.g. biocides and fungicides, are not necessary at all, since microbial growth is possible only in an aqueous phase. It reduces health hazards caused by emissions of metalworking fluids on the skin of employees at their workplaces. Metalworking fluids do not spread throughout the area around the machine, thus making for a cleaner workplace. The present work experimentally investigates the role of MQL on surface roughness of material with help of timer-based controlling in machining process.

In machining operation, the quality of surface finish is an important requirement of work pieces and parameter in manufacturing engineering. The main objective of the cutting fluid in hard turning is to serve as coolant as well as lubricant due to more heat generation in machining. Turning requires large quantities of coolants and lubricants that is why the total cost of production increases considerably. However, the advantages caused by the cutting fluids have been questioned lately, due to the several negative effects they cause. When inappropriately handled, cutting fluids may damage soil and water resources, causing serious loss to the environment. The operators may be affected by the bad effects of cutting fluids, such as by skin and breathing problems. Due to the multiplicity of being negative effects the cutting fluid wastes produce on mankind and our environment. Therefore, in modern production there has been an increasing attention to carefully selection of efficient cutting fluids and its application method that would in addition to being efficient be also environment friendly. Therefore, manufacturers as well as end users should find it in their common interest to develop new kinds of cutting fluids whose quality will be identifiable in terms of machinability parameters as well as ecological parameters.

It is found from literature that the various approaches have been tried by the researchers in this regard. It is known fact that a conventional application of flood coolant has limitations and hampers the machining productivity if the input parameters are not properly controlled and monitored. Thus, the new technique that reduces the above draw backs are used by few authors. These approaches are Minimum Quantity Lubrication (MQL), cryogenic lubrication and coolant and water vapor as coolant. A study of performance in machining of different materials with dry, wet, MQL and cryogenic cooling is available in open literature. The review of the literature shows that minimum quantity lubrication provides more benefits in machining. The objective of the work is to experimentally detecting the role of minimum quantity lubrication (MQL) on surface roughness, cutting force, cutting temperature and tool wear in turning AISI-4340 steel at industrial speed-feed condition by coated carbide insert and compare the various parameters of MQL with that of dry and wet machining. Minimum quantity lubrication is an alternative to reduce the tool wear, friction and hence prevent the adherence of the material. The consumption of the cutting fluid in minimum quantity lubrication is generally less than 500 ml/hr.

II. EXPERIMENTAL SETUP

Experiments were carried out on CNC Lathe available in the departmental lab. Computer numerical control (CNC) is the automation of machine tools by means of computers executing pre-programmed sequences of machine control commands. This is in contrast to machines that are manually controlled by hand wheels or levers, or mechanically automated by cams alone. In modern CNC systems, the design of a mechanical part and its manufacturing program is highly automated. Air compressor is used to obtain compressed air at different pressures. MQL device by Dropsa, Italy is used for generating mist to be utilized for cooling and lubrication purpose at the cutting tool-work interface.

The Filter-Regulator-Lubricator (FRL) unit was used to control air pressure and enable to have a constant supply at fixed pressure for the MQL and further to cutting zone. Vegetable based cutting oil is used as liquid phase in a two-phase mixture obtained from MQL, compressed air being the gaseous phase. Carbide inserts were used for machining. Cylindrical HCHCR steel components of 100 mm length and 40 mm diameter were used as work material. Turning operations were performed to determine surface roughness (SR) and Material removal rate (MRR) as response characteristics. Taguchi's L_{27} (3^{13}) orthogonal array is used for conducting experiments. As per array 27 experiments were performed at different parametric combinations. Process parameters and their levels are presented in Table 1.

Fig. 1 CNC Lathe used for experimentation

Table 1 Parameters and their levels used in the L_{27} (3^{13}) orthogonal experiment

	Experimental Parameter	Symbol (Units)	Levels		
			Level 1	Level 2	Level 3
A	Air Pressure	P (bar)	5	6	7
B	Depth of cut	DOC (mm)	0.50	0.75	1.00
C	Feed rate	s (mm/ rev)	0.25	0.50	0.75
D	Speed	N (rpm)	300	500	700
E	Flow rate	f (ml/min)	2	4	6

III. RESULTS AND DISCUSSIONS

Table 2 presents experimental results based on Taguchi's L27 Orthogonal array design. Performance characteristics viz. MRR and SR are measured in cc/min and µm respectively. Statistical software Minitab 17 is used to determine main effects plots, analysis of variance and residual plots.

Taguchi experimental design that extensively uses orthogonal arrays is an efficient tool for improving process/product quality with relatively less number of experimental runs. The method can optimize performance characteristics through determination of best parameter settings and reduces the sensitivity of the system performance to sources of variation. Orthogonal arrays provide a set of well-balanced experiments with less number of experimental runs. The appropriate array for this case is L27 Orthogonal as above.

Effect of process parameters on MRR

From Fig. 2 Main Effects plot for SN ratio of MRR, it is found that the duty cycle has inverse relationship with MRR as the increase in air pressure from 5 to 6 bar MRR decreases proportionally and thereafter increases till 7 bar. Depth of cut, feed rate and speed has direct relationship with MRR. Within the experimental ranges of these parameters increased parametric values cause increase in the MRR proportionally. It is quite obvious owing to the increased levels of parameters. Whereas oil flow rate has a very little effect on MRR. Oil Flow rate of 4 ml /min is found to have slightly better results in terms of MRR.

The residual plots shown in Fig. 3 do not show any particular pattern in the residuals, which are the characteristics of reliable data. Normal probability plot depicts the residuals with outliers.

The inferences made from the main effects plot for MRR are in agreement with the p-values obtained in the ANOVA shown in Table 3.

Table 2 Experimental results using an Taguchi's L_{27} Orthogonal array

Exp. run	Process parameters					Response parameters	
	Air pressure	Depth of cut	Feed Rate	Speed	Flow rate	MRR (cc/min)	SR (Ra in µm)
1	5	0.5	0.25	300	2	3.8887692	0.4066667
2	5	0.5	0.25	300	4	4.6905773	0.38
3	5	0.5	0.25	300	6	4.6550645	0.34
4	5	0.75	0.5	500	2	27.10134	1.3066667
5	5	0.75	0.5	500	4	23.615667	0.57
6	5	0.75	0.5	500	6	24.433231	0.4566667
7	5	1	0.75	700	2	58.882731	0.5766667
8	5	1	0.75	700	4	67.528916	1.4733333
9	5	1	0.75	700	6	54.284746	0.71
10	6	0.5	0.5	700	2	23.025607	0.79
11	6	0.5	0.5	700	4	22.42415	0.6633333
12	6	0.5	0.5	700	6	19.91186	1.5833333
13	6	0.75	0.75	300	2	20.134725	1.22
14	6	0.75	0.75	300	4	20.700687	1.2633333
15	6	0.75	0.75	300	6	14.068387	1.7266667
16	6	1	0.25	500	2	15.667086	0.37
17	6	1	0.25	500	4	15.467127	0.6333333
18	6	1	0.25	500	6	16.984545	0.3366667
19	7	0.5	0.75	500	2	23.356571	0.85
20	7	0.5	0.75	500	4	23.213571	0.57
21	7	0.5	0.75	500	6	21.103247	1.4966667
22	7	0.75	0.25	700	2	16.46497	0.39
23	7	0.75	0.25	700	4	16.533272	0.3166667
24	7	0.75	0.25	700	6	14.979737	1.4133333
25	7	1	0.5	300	2	18.007711	0.6266667
26	7	1	0.5	300	4	18.467545	0.5
27	7	1	0.5	300	6	18.605477	0.4333333

Air pressure, depth of cut, feed rate and speed are found to be statistically significant parameters as p-value>0.05 for all these factors at 95% confidence level. They are the major contributing factors in improvement of MRR. Feed rate has the maximum contribution (37%) followed by speed, depth of cut and air pressure respectively. Pie chart shown in fig. 6 a. presents the contribution of all factors including error. It is evident that the error % has very little contribution in comparison with the parameters.

Table 3 Analysis of variance (MRR)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Air Pressure	2	734	367	57.08	0	12.93
Depth of Cut	2	1153.97	576.98	89.73	0	20.33
Feed Rate	2	2098.14	1049.07	163.15	0	36.96
Speed	2	1644.19	822.1	127.85	0	28.96
Flow rate	2	33.39	16.69	2.6	0.106	0.59
Error	16	102.88	6.43			0.23
Total	26	5766.56				

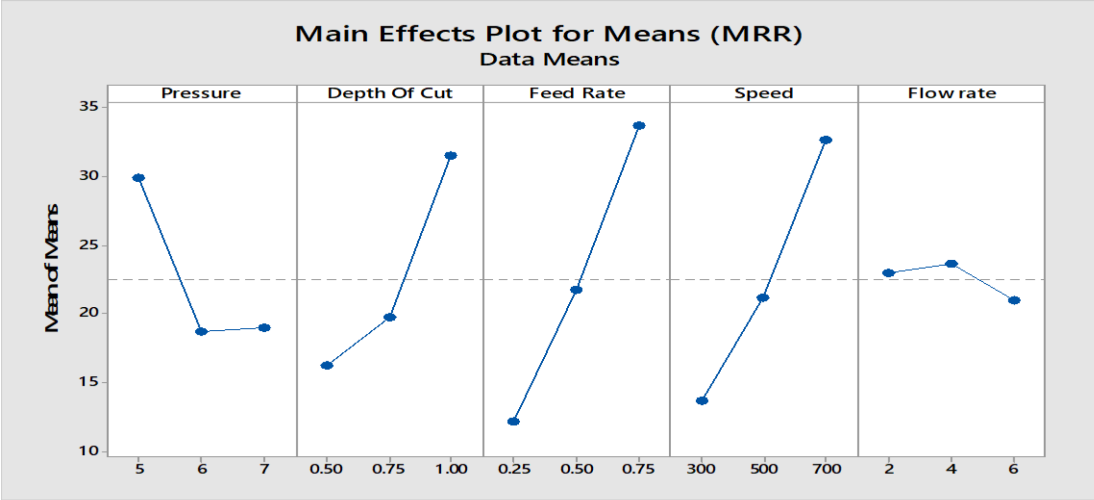

Fig. 2. Main effects plot (MRR)

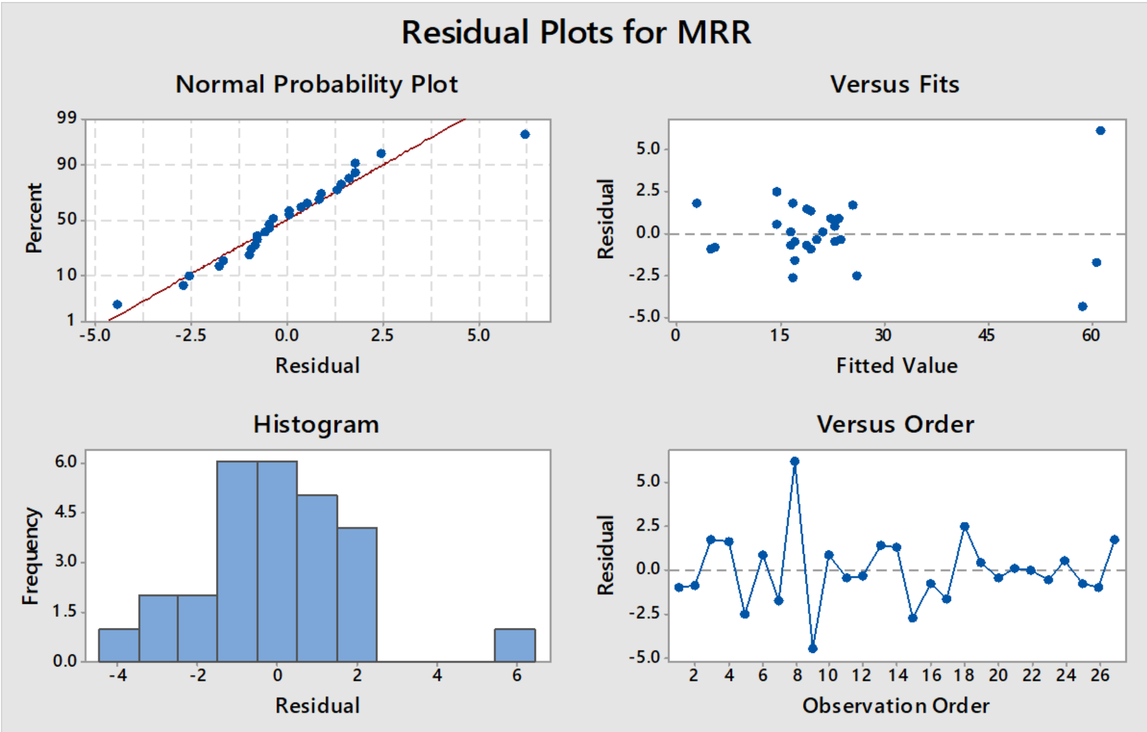

Fig. 3 Residual plot for MRR

Effect of process parameters on SR

Main effects plot for SR presented in Fig. 4 shows that feed rate has direct relationship with the surface roughness. Slight increase in the feed rate deteriorates the surface quality remarkably. With increase in air pressure and depth of cut initially from 5 to 6 bar and from 0.5 to 0.75 mm respectively decreases surface quality. On further increasing these factors, surface quality improves. Lower flow rates and speed provides good surface quality.

Residual plots for SR presented in Fig. 5 do not show any non-random identifiable pattern in the residuals, which are the characteristics of good model reliability.

ANOVA presented in Table 4 shows that only feed rate is the statistically significant at 95% confidence level and maximum contributes in the improvement of surface finish. Other factors have very little contribution for SR. Fig. 6 b. presents pie chart to show the contribution of all the factors. Feed rate has the major contribution (62%) for SR followed by oil flow rate, air pressure, depth of cut and speed. Traditionally it is understood that speed has direct bearing on surface quality. In this study the speed range taken may not be enough to discriminate the results.

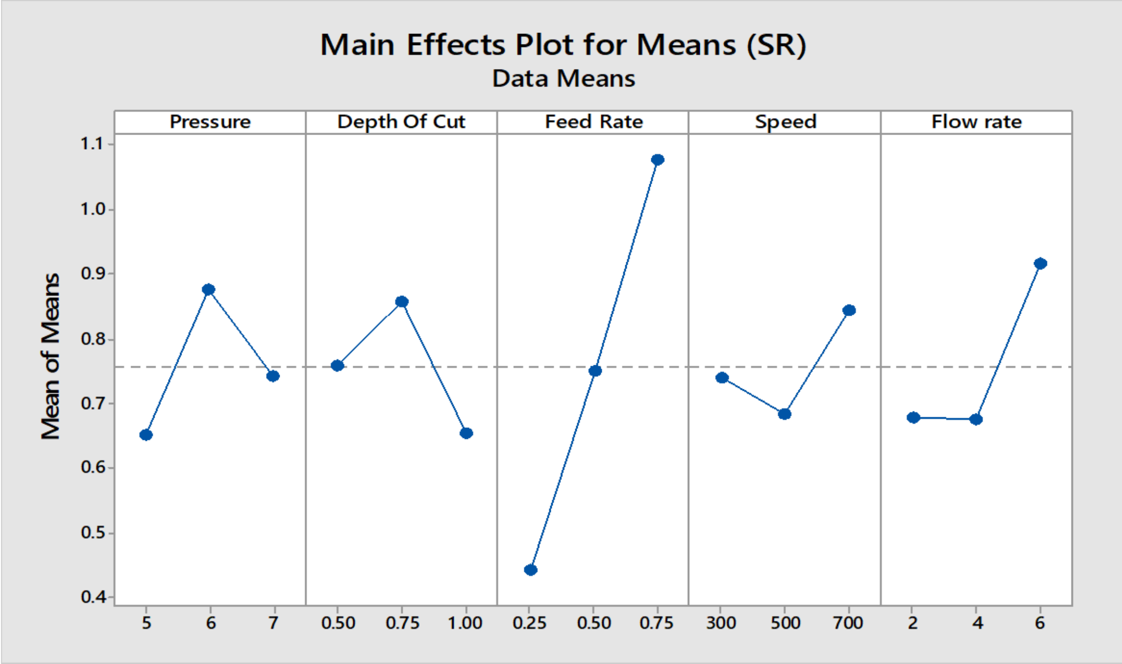

Fig. 4 Main effects plot (SR)

Table 4 Analysis of variance (SR)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Air Pressure	2	0.2321	0.11603	0.94	0.412	7.87
Depth of Cut	2	0.1841	0.09203	0.74	0.491	6.24
Feed Rate	2	1.8184	0.90921	7.35	0.005	61.69
Speed	2	0.1188	0.05939	0.48	0.627	4.03
Flow rate	2	0.3473	0.17363	1.4	0.274	11.78
Error	16	1.9785	0.12366			8.39
Total	26	4.6791				

Optimal level settings are obtained for improving MRR and SR individually based on main effects plot and presented in Table 5. Confirmation experiments are done at these setting to validate the predicted results. Predicted responses and experimental results presented in the table below. Errors between predicted and experimental results are found to be 1.71% and 8.76% for MRR and SR respectively.

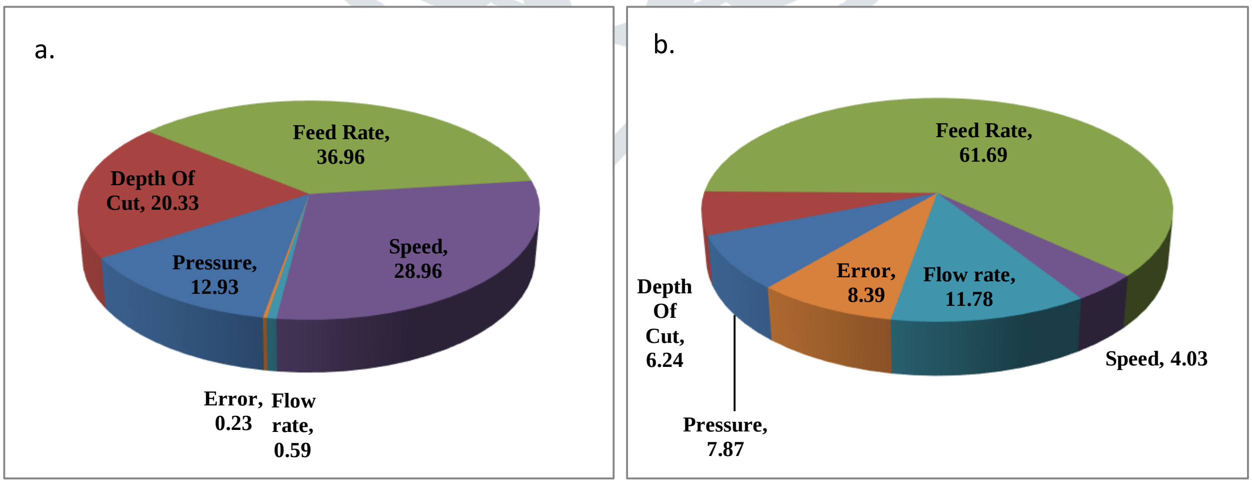

Fig. 6 Percentage contribution for a.MRR b.SR

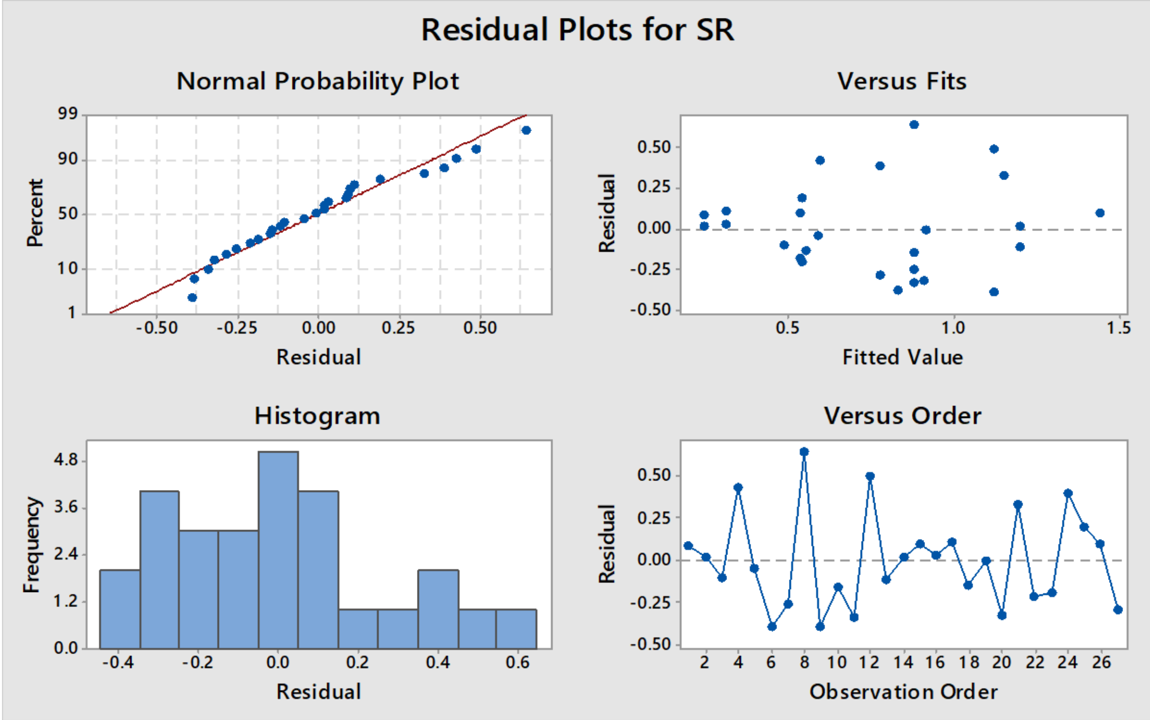

Fig. 5 Residual Plots for SR

Table 5 Optimal level setting and error between predicted and experimental results

	MRR (mm3/min))	SR (µm)
Optimal level settings	A1B3C3D3E2	A1B3C1D1E2
Predicted	28.329	0.0825926
Experimental	27.852	0.0905258
% Error	1.7126	8.7635

IV. Conclusions

The findings in near-dry turning of HCHCR with carbide tool and two phase dielectric media are as follows:
1. Air pressure, depth of cut, feed rate and speed are found to be most significant and critical parameters that affect MRR. Feed rate is found to be only statistically significant parameter that affects SR.
2. Taguchi method can be used effectively to optimize single response characteristic viz. MRR and SR. % error between results predicted based on Taguchi method and experimental results is negligible.
3. Feed rate contributes maximum (62%) in improvement of SR followed by oil flow rate, air pressure, depth of cut and speed respectively.
4. Feed rate has the maximum contribution (37%) in improvement of MRR followed by speed, depth of cut and air pressure respectively.

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