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Optimization of Cutting parameters of AISI 1018 Low Carbon Mild steel in turning using green cutting fluid by Taguchi Method

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Abstract - The objective of this work is to optimize the response Cutting parameters (Tool wear and Material Removal Rate) of AISI 1018 Low carbon mild steel by Taguchi Method in straight turningprocess. We have taken speed, feed, depth of cut and types of cutting fluids as machining parameters with their three level values. In our study a commercial semi-synthetic cutting fluid (SSCF) and two vegetable based cutting fluids are used and values of response variables are analyzed to see if the performance of response machining parameters is increased by using Vegetable based cutting fluids for sustainable machining.For individual optimization,Taguchi's $L_9(3^4)$ orthogonal array and Analysis of Variance(ANOVA) are used. The optimum results are verified with the help of confirmation test.

Keywords - **ANOVA, MRR, Tool wear,Taguchi method,Turing, green cutting fluid**.

INTRODUCTION

Turning is a process of removing metal from outer surface of a rotating cylindrical workpiece. The turning process requires a Lathe, fixture, workpiece (preferably cylindrical) and cutting tool. In turning process, job or the workpiece is held to the rotating chuck and a typically single-point cutting tool (harder than workpiece) is used to reduce the diameter of cylindrical job. In competition market, each and every manufacturing and production industry wants to manufacture at low cost and high quality product within required time to meet customer demand and satisfaction. Thus, optimization of cutting parameters is required to utilize the maximum use of raw material and earn profit. AISI 1018 Mild steel is used in forged motor shafts, pump shafts, hydraulic shafts and different machinery parts. Machining of AISI 1018 is difficult as it has high strength and hardness. Chances of generating poor surface finish, high force and tool wear are very much. So cutting fluid is generally used to eliminate detrimental effects during machining. Cutting fluids not only carries away the generated heat but also provide lubrication between the chip-tool interfaces and flushes away the chips. Today a wide variety of synthetic and semi-synthetic cutting fluids are available in the market. But considering to environmental effects and health of workers, green cutting fluids from various vegetable oils may be used on different machining process as cutting fluids.

Verma [1] studied the experiments using Taguchi L_9orthogonal array design with speed, feed, and depth of cut as input parameters and surface roughness and MRR as output variables at dry machining condition of 16MnCr5 material. Das et al. [2] considered optimization process of the cutting parameters (speed, feed and depth of cut) in dry turning of AISI D2 steel to attainlow work-piecesurface temperature and minimum tool wear. The experimental design was based on the Taguchi's L_9 (3^4) Orthogonal array procedure and analysis of variance (ANOVA) was performed to find the outcome of the cutting parameters on the response variables. The minimum tool wear was obtained at cutting speed of 150 m/min, feed of 0.25 mm/revand depth of cut of 0.5 mm. Likewise low work-piece surface temperature was found at cutting speed of 150 m/min, feed of 0.25 mm/revand depth of cut of 0.5 mm. Finally, multipleregression analysis was performed to find the relationship between cutting parameters and the performance measures. Chandrasheker et al. [3] presents an effectiveapproach for the optimization of turning parameter usingthis machining parameters namely Cutting Speed, Depth of Cut, Feed Rate and cutting fluids are optimized withmultiple performance characteristics, such as minimum surface finish and maximummaterial removal rate [4]. The-response table and response chart for each level of machiningparameters are from the Taguchi Method and theoptimum levels of machining parameters are chosen.Kumar, et al. [5] provided us the optimized value of cutting parameters for turning AISI 316 stainless steel to achieve the better surface finish or roughness using Taguchi's Total 9 experiments using L_9 (3^4) Orthogonal Array by using four control factors i.e. cutting speed, depth of cut, feed rate and three different cutting fluids (straight cutting oil, sherol B, sherol ENF) and work piece material (AISI 316 stainless steel) and the turning operations are done on Banka 1000 lathe machine. According to their experiment, cutting speed followed by cutting fluid has the significant role. The test results using "smaller-the-better" criteria for Signal-to-Noise ratio has been used

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in order to optimize the process. Yang et al. [6] used the Taguchi method [7] to findbest cutting parameters in turning operations to study the cutting properties of S45C steel bars bycutting tools made of tungsten carbide. During this study, the optimal cutting parameters for turning operations and main cutting parameters affecting the machining performance in turning operations can be obtained. An experiment was performed to validate the effectiveness of this method. Nayak et al. [9] has studied to identify the influence of cutting parameters such as cutting speed(S),depth of cut(D)and feed (F) on different parameters (material removal rate, cutting force and surface roughness) measuredthrough dry turning of AISI 304 (austenitic stainless steel). Orthogonal array (L27) design of experiments was performed with machining parameters'= 25, 35, 45 m/min.,D=1, 1.25, 1.5 mmand F=0.1, 0.15, 0.2 mm/rev. Further, grey relational analysis [8] was performed to simultaneously optimize the output machining parameters. The optimum value of input parameters wereS= 45m/min, D=1.25mm and F=0.1mm/rev. There was improvement of 88.78% in grey relational grade (GRG) in Confirmatory test.Sridhar et al. [10], studied optimization of cutting parameters of cutting speed, depth of cutand feedin turning of EN8 steel on lathe using TaguchiL_9 orthogonal array and Grey Relational to minimize cutting forces and surface roughness. Analysis of variance (ANOVA) shows that the most significant factor affecting the cutting force and surface roughness is depth of cut, followed by a feed, speed and cutting fluid.

MATERIALS AND METHOD

Workpiece

Work piece material used in this project was three pieces of AISI 1018 mild/low carbon steel of length 150 mm. (approx.) and diameter of 35 mm. (approx.).

Cutting Tool

HSS (High speed Steel) of Type T-1 is used as tool which is mounted on the lathe machine. The basic composition of the High speed Steel is 18% W (Tungsten), 4% Chromium,1% vanadium,0.7% Carbon and rest is Fe.This type of HSS tool can machine (turn) mild steel jobs at a speed of 20-30 m/min under dry cut and upto 45 m/min with fluid cutting.

Lathe Machine

The cutting experiments were performed on a high-speed precision& semi-automatic center Lathe (HMT, Model No-NH22).

EXPERIMENTAL PROCEDURE

Tool wear Measurement

Tool flank wear was measured using Digital Vernier, least cost .01 mm.

MRR measurement

Material Removal rate was determined from the difference of the volume of workpiece before machining and after machining by applying the following formula:

$$MRR=\frac{\text{Volume Removed}}{\text{Cutting time}}=\frac{\pi*L*(\mathbf{d1^2-d2^2})}{\frac{4L}{fN}}\ \text{mm}^3/\text{sec}$$

Where, d_1 and d_2 denote the diameters before machining and after machining respectively, L implies the length of machining zone of the workpiece and N denotes the spindle speed.

Taguchi Method

The objective of the Taguchi method is to evaluate an optimal combination of parameters that bears the smallest deviation in performance. The signal-to-noise ratio (S/N ratio, η) is a significant way to determine the influencing parameters by calculating minimum variance. A higher S/N ratio signifies better performance for combinatorial parameters-

$$\text{S/N ratio} = -10\log_{10}\left[\frac{1}{n\times|{y_i}^2|}\right] \quad (1)$$

$$\text{S/N ratio} = -10\log_{10}\frac{|{y_i}^2|}{n} \quad (2)$$

Equation (1) is used for the 'larger-the-better' responses and Equation (2) is used for the 'smaller-the-better' responses. Besidesadopting the S/N ratio approach, some authors like Lin and Lin 2002, Fung 2003, applied the mean of the simulation results of all the replications for optimization. Therefore, the present research also successfully optimized the mean value for comparison. The layout of the Experiment, using an L_9 orthogonal array (Up to 4 factors) is shown in the following Table 1.

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Table 1. Experiment lay out.

Experiment no.	Parameters with levels			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

RESULTS AND ANALYSIS

Here, MINITAB software is used for analyzing the experimental work. The Minitab software deals with the experimental data and compiles it, and then it evaluates the equations of surface roughness for a work piece material. After analyzing the set of data, for the surface roughness related on the several factors cutting speed, feed rate, depth of cut, cutting fluid for a work piece material i.e., AISI 1018 Mild steel is given in following Table No. 2.

Table 2. Surface roughness factors.

Run no	V	F	D	Cutting Fluid	TOOL WEAR(mm)	MRR (mm^3/sec)
1	250	0.08	0.5	SSCF	0.12	2198.15977
2	250	0.16	1.0	Soya bean oil	0.15	3795.496
3	250	0.20	1.5	Mustard oil	0.10	7520.9728
4	420	0.08	1.0	Mustard oil	0.24	3489.9595
5	420	0.16	1.5	SSCF	0.18	9333.885
6	420	0.20	0.5	Soya bean oil	0.28	6280.793
7	550	0.08	1.5	Soya bean oil	0.19	6569.5135
8	550	0.16	0.5	Mustard oil	0.30	7222.816
9	550	0.20	1.0	SSCF	0.34	9989.3428

Taguchi Analysis

Tool wear (TW) versus speed, feed, DOC, CF response Table for signal to noise ratios and ANOVA Table for tool wear (TW) are shown in Table 3, 4 respectively, Plot for main effects of the S/N Ratio on tool wear is shown in Fig 1.

Table 3. Tool wear details.

Level	Speed	Feed	DOC	CF
1	**18.30**	**15.08**	13.31	14.23
2	12.78	13.94	12.75	**14.28**
3	11.42	13.48	**16.44**	13.99
Delta=max-min	6.88	1.60	3.69	.30
Rank	1	3	2	4

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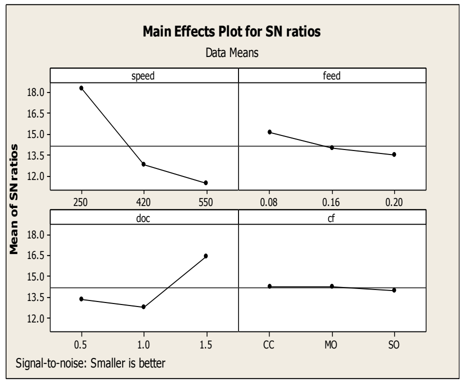

Fig. 1. Effects of the S/N Ratio on Tool wear.

Optimum Combination for Tool Wear

SPEED = 250 rpm, FEED = 0.08mm/rev, DOC = 1.5 mm, CF = Mustard oil (MO).

Table 4. Optimum Combination for Tool Wear

Control Factors	Degrees of freedom	Sum of Squares	Mean squares	% of contribution
Speed	2	0.0374889	0.0187444	67.07
Feed	2	0.0048222	0.0024111	8.62
DOC	2	0.0134889	0.0067444	24.13
Cutting Fluid	2	0.0000889	0.0000444	0.16
Error	0	-	-	
Total	8	0.0558889		100

Taguchi Analysis

Material Removal Rate (MRR) versus Speed, Feed, DOC, CF

Response Table for signal to noise ratios and ANOVA Table for material removal rate (MRR) are shown in Table 5, 6 respectively, main effects plot for S/N Ratio on Material Removal Rate (MRR) is shown in Fig 2.

Table 5. Material removal rate (MRR).

Level	Speed	Feed	DOC	CF
1	71.98	71.35	75.33	**75.41**
2	75.41	76.05	74.14	75.19
3	**77.84**	**77.83**	**77.76**	74.63
Delta=max-min	5.85	6.48	4.43	0.78
Rank	2	1	3	4

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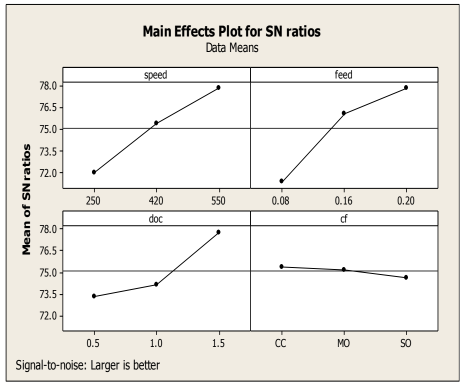

Fig. 2. Effects of the S/N Ratio on MRR.

Optimum Combination for MRR

SPEED = 550 rpm, FEED = 0.20 mm/rev, DOC = 1.5 mm, CF = SSCF

Table 6. ANOVA Table for material removal rate (MRR).

Control Factors	Degrees of freedom	Sum of Squares	Mean squares	% of contribution
Speed	2	17615005	8807502	31.33
Feed	2	23374350	11687175	41.58
DOC	2	11103362	5551681	19.75
Cutting Fluid	2	4122386	2061193	7.33
Error	0	-	-	
Total	8	56215103		100

Confirmatory Experiment

Conducting an experiment for further verification is a crucial factor of the robust design methodology. The predicted result should be conformed to the verification test with the optimum set of conditions,

Confirmatory Experiment for Tool Wear

In the final step the optimum cutting conditions for Tool Wear of cutting speed at 250rpm (A1), Feed at 0.08mm/rev (B1), DOC 1.5mm (C3) and cutting fluid is Mustard oil (D3).

$\eta_{predicted}$ = [A1+B1+C3+D2]-3η=(18.30+15.08+16.44+14.28)-(3*14.16667) = 64.1-42.5 = 21.6

η = average of all S/N ratios = (18.30+15.08+13.31+14.23+12.78+13.94+12.75+14.28+11.42+13.48+16.44+13.99)/12 =170/12=14.16667

Corresponding predicted TW= 0.085 mm
Predicted and confirmation test for Tool Wear are shown in table 7.

Table 7. Predicted and confirmation test for Tool Wear.

$TW_{predicted}$	0.085 mm
$TW_{confirmation\ test}$	0.12 mm
% variation	29.16%

Confirmatory Experiment for MRR

In the final step the optimum cutting conditions for Tool Wear of cutting speed at 550rpm,Feed at 0.20 mm/rev, DOC 1.5 mm and cutting fluid is semisynthetic cutting fluid i.e. Veedol Solucut Super.

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$\eta_{predicted}$ = [A3+B3+C3+D3]-3η=(77.84+77.83+77.76+75.41)-(3*75.243) =308.84-225.729=83.111

η = average of all S/N ratios = (71.98+75.41+77.84+71.35+76.05+77.83+75.33+74.14+77.76+75.41+75.19+74.63)/12 =902.92/12=75.24

Corresponding predicted MRR = 15153mm³/sec
Predicted and confirmation test for MRR are shown in table 8.

Table 8. Predicted and confirmation test for MRR.

$MRR_{predicted}$	15153mm³/sec
$MRR_{confirmationtest}$	15962.6022 mm³/sec
% variation	5.1%

CONCLUSION

This study extends an application of the Taguchi Method for determining the influence of Turning Parameters and cutting fluid types on Tool Wear and MRR of AISI 1018 Low carbon Mild steel. In the turning experiments, different, Feed rate, cutting Speed, Depth of cut and Cutting Fluid were utilized. Taguchi S/N ratio and Orthogonal Analysis and ANOVA were performed to decide which factor has most and less influence on the response parameters. Based on the study, the following conclusions can be made:
1. The experimental results revealed that the Taguchi parameter design is an effective way for evaluating the optimal cutting parameters for gaining low Tool Wear and high MRR.
2. The percentage contributions of Cutting Speed (67.07%) and Depth of cut (24.13%) in affecting& enhancing the variation of Tool Wear are significantly larger compared to Feed Rate (8.62%) and Cutting Fluid (0.16%).
3. The significant parameters for MRR were Feed Rate and Cutting Speed with weightages of 41.58% and 31.33% respectively. Although not statistically dominant, Depth of cut and Cutting Fluid have physical influences explaining 19.75% and 7.33% of the total variation respectively.
4. The best parameter combinations for optimal tool wear are: Speed (A) at Level-1 (250rpm), feed (B) at level 1 (0.08 mm/rev), Depth of cut (C) at level 3 (1.5 mm) and Cutting Fluid at level 2 (mustard oil)
5. Best parameter combinations for optimum material removal rate are: Speed (A) at level 3 (550 rpm), feed (B) at level 3 (0.20 mm/rev), Depth of cut (C) at level 3 (1.5 mm) and cutting fluid (D) at level 1 SSCF (semi-synthetic water emulsified cutting fluid, Veedolsolucut Super).

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