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An Experimental Analysis of Surface Roughness of EN9 Steel under the influence of Pressurized Steam Jet

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Abstract- **This paper discusses the ideal solution for minimizing surface roughness in grinding operation on EN9 steel by using pressurized steam jet as a coolant and analyse it using Grey Relational Analysis methodology. The collective analysis of the measured results were performed with the help of commercial software package Minitab 17 and the experiments were conducted using L_{18} orthogonal array experimental design technique. The test conditions matrix included three different values of steam pressures, two different values of feed rates, three different values of depth of cut and three surface treatment conditions which were used as parameters during grinding operation, while cutting speed was kept constant at 2840 rev/min. The determination of optimum cutting conditions for minimizing the surface roughness was observed analytically under the effect of different cutting parameters on surface roughness. The experimental results revealed that the optimal combination of machining parameters for obtaining minimum surface roughness was in the sequence of depth of cut followed by pressurized steam jet, feed rate and annealing surface treatment. The predicted values and measured values were found to be fairly close, which indicates that the developed model can be effectively used.**

***Keywords*- ANOVA, Pressurized Steam Jet, Surface Roughness, Grinding, Grey Relational Analysis, Orthogonal Array, Surface Treatment Condition.**

I. Introduction

Surface grinding is used to produce a smooth finish on flat surfaces. It is widely used in abrasive machining process in which a spinning wheel covered in rough particles (grinding wheel) cuts chips of metallic or non metallic substance from a work piece, making a face of it flat or smooth.

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Grinding process is one of the essential machining operations carried in any industry as it plays an important role of metal removing process as well as contributes towards obtaining better surface finish of ground component. Surface roughness plays a vital role in defining the character of a surface. Several functional attributes of parts, such as friction, wear and tear, light reflection, heat transmission, corrosion, ability of distributing and holding a lubricant, coating etc effect the surface roughness. Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough. If they are small the surface is smooth. The smoothness of surface depends on many factors these include: work material properties, grinding wheel composition, dressing, operation parameters, coolant application and properties, and machine vibrations. Grinding is considered to account for 15-20 % of manufacturing cost of finished product and therefore in order to achieve minimal expenses or minimal production time, it is essential to determine optimal cutting parameters.

Heat Treatment is used to alter the physical and chemical properties of materials. It improves the quality in terms of microstructures and surface roughness. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering and quenching. Heat treatment provides an efficient way to manipulate the properties of the metal by controlling the rate of diffusion and the rate of cooling within the microstructure. Heat treating is often used to alter and manipulate the mechanical properties such as the hardness, strength, toughness, ductility, and elasticity of an alloy.

[Podgorv (1992) and Godelvski et al. (1998)] proposed a pollution free eco-friendly grinding technique involving water vapour (or steam) as coolant and lubricant during grinding process in 1990. During machining the steam jet was adapted to produce dominant effect for cutting of materials as discovered by Li Seah(2001); Li (1996); Kaminski and Alveid (2000); Shetty et al. The pressurized steam jet has been very prominent factor promoting a significant reduction of heat generated in cutting region and cutting force resulting in high surface finish.

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II. Research Methodology

A. *Grey Relational Analysis*

Deng proposed Grey relational analysis in 1989 which is being widely utilized for measuring various degree of relationship between sequences by grey relational grade. Several researchers employ Grey relational analysis to optimize control parameters having multi-responses through grey relational grade. To optimize the surface grinding operation Taguchi method with grey relational analysis is used with multiple performance characteristics.

B. *Experimental Details and Observations*

A setup for generating pressurized steam jet was developed for carrying out the experiments. All experiments have been carried out on surface grinding machine.

The workpiece material used was EN9 steel. The dimensions of the workpiece were 100 mm × 100 mm × 7 mm.
The chemical composition of EN9 steel is shown in Table I respectively.

Figure 1 Steam Generator

TABLE I
CHEMICAL COMPOSITION OF EN9 STEEL

Element	C	Si	Mn	S	P
% Wt	0.50%	0.25%	0.70%	0.05%	0.05%

The process parameters employed during the experiment as given in Table II.

TABLE II
EXPERIMENTAL FACTORS AND THEIR LEVELS

Feed Rate(mm/rev)	1.5		2.0
Depth of Cut(mm)	0.3	0.5	0.7
Pressurized Steam Jet(kg/cm^2)	2.0	3.0	4.0
Surface Treatment Condition	WHT	HTHT	AHT

Where,

WHT - Without Heat Treatment

HTHT- Hardening followed by Tempering Heat Treatment

AHT - Annealing Heat Treatment

Construction of L_{18} orthogonal array was carried out in order to predict the surface roughness and to optimize the multiple performance characteristics of the surface grinding. Selected design matrix is shown in Table III.

TABLE NO.III
STANDARD L18 ORTHOGONAL ARRAY

Exp. No.	Feed Rate	Depth of Cut	Pressurized Steam Jet	Surface Treatment Condition
1.	1	1	1	1
2.	1	1	2	2
3.	1	1	3	3
4.	1	2	1	1
5.	1	2	2	2
6.	1	2	3	3
7.	1	3	1	1
8.	1	3	2	2
9.	1	3	3	3
10.	2	1	1	1
11.	2	1	2	2
12.	2	1	3	3
13.	2	2	1	1
14.	2	2	2	2
15.	2	2	3	3
16.	2	3	1	1
17.	2	3	2	2
18.	2	3	3	3

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Orthogonal array consisting of 18 sets of coded conditions and the experimental results for the response of surface roughness (R_a) is shown in table IV. All these data are used for the analysis and evaluation of the optimal levels of the parameters combination.

TABLE NO.IV

EXPERIMENTAL RUN AND RESULTS

Exp .No.	Feed Rate (mm /rev)	Depth Of Cut (mm)	Pressurized Steam Jet (kg/cm^2)	Surface Treatment Condition	Surface Roughness R_a (μm)
1.	1.5	0.3	2	WHT	0.039
2.	1.5	0.3	3	HTHT	0.059
3.	1.5	0.3	4	AHT	0.030
4.	1.5	0.5	2	WHT	0.039
5.	1.5	0.5	3	HTHT	0.059
6.	1.5	0.5	4	AHT	0.059
7.	1.5	0.7	2	WHT	0.058
8.	1.5	0.7	3	HTHT	0.059
9.	1.5	0.7	4	AHT	0.059
10.	2	0.3	2	WHT	0.058
11.	2	0.3	3	HTHT	0.079
12.	2	0.3	4	AHT	0.040
13.	2	0.5	2	WHT	0.049
14.	2	0.5	3	HTHT	0.079
15.	2	0.5	4	AHT	0.059
16.	2	0.7	2	WHT	0.079
17.	2	0.7	3	HTHT	0.079
18.	2	0.7	4	AHT	0.069

The grinding operation was carried on surface grinding machine. Digital Surface Roughness Tester TR 110P was used to measure average surface roughness.
Electric furnace was used for the heat treatment of workpieces.

C. *Analysis of Observations*

2.3.1 Best Experimental Run

The experimental results for surface roughness (R_a) are listed in the Table IV. Typically, smaller values of R_a are desirable. Thus the data sequences have the smaller-the-better characteristic, the "smaller-the-better"

methodology, i.e. Equation (1), was employed for data pre-processing.

$$x_i^*(k) = \frac{max\ x_i^{(0)}(k) - x_i^{(0)}(k)}{max\ x_i^{(0)}(k) - min\ x_i^{(0)}(k)}$$

Where max $x^{(0)}(k)$ and min $x^{(0)}(k)$ are the maximum and minimum values respectively of the original sequence $x_1^{(0)}(k)$. Comparable sequence x*(k) is the normalized sequence of original data.

Next step is the calculation of deviation sequence, Δoi(k) from the reference sequence of pre-processes data x*(k) and the comparability sequence x*(k). The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$y(x_0^*(k), x_i^*(k)) = \frac{\Delta min + \xi \Delta max}{\Delta oi(k) + \xi \Delta max} 0 < y(x_0^*(k), x_i^*(k)) \leq 1$$

TABLE NO. V

DATA PRE-PROCESSING RESULT

Comparability Sequence	Reference Sequence
Run No.	Ra
No.1	0.82
No.2	0.41
No.3	1.00
No.4	0.82
No.5	0.41
No.6	0.41
No.7	0.43
No.8	0.41
No.9	0.41
No.10	0.43
No.11	0.00
No.12	0.80
No.13	0.61
No.14	0.00
No.15	0.41
No.16	0.00
No.17	0.00
No.18	0.20

This investigation employs the response table to calculate the average Grey relational grades for each factor level, as illustrated in Table VI. Since the Grey relational grades represented the level of correlation between the reference and the comparability sequences, the larger Grey relational grade means the comparability sequence exhibiting a stronger correlation with the reference sequence.

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TABLE NO. VI
CALCULATION OF GRADE

S. No.	Feed Rate (mm/rev)\A	Depth of Cut (mm) B	Pressurised Steam Jet (kg/cm^2) C	Surface Treat -ment Condition D	Grade
1.	1	1	1	1	0.7352
2.	1	1	2	2	0.4587
3.	**1**	**1**	**3**	**3**	**1.0000**
4.	1	2	1	1	0.7352
5.	1	2	2	2	0.4587
6.	1	2	3	3	0.4587
7.	1	3	1	1	0.4672
8.	1	3	2	2	0.4587
9.	1	3	3	3	0.4587
10.	2	1	1	1	0.4672
11.	2	1	2	2	0.3333
12.	2	1	3	3	0.7142
13.	2	2	1	1	0.5617
14.	2	2	2	2	0.3333
15.	2	2	3	3	0.4587
16.	2	3	1	1	0.3333
17.	2	3	2	2	0.3333
18.	2	3	3	3	0.3846

2.3.2 Most Influential Factor

Grey relational analysis was employed to find out most influential factor among the grinding process parameters that affect the surface roughness. The values of the factor level in eighteen experimental runs were set to be the comparability sequences for four controllable factors as shown in Table VII. Data pre-processing was employed, and the normalized results were tabulated in Table no. VII.

The deviation sequences were calculated using the same method above. To obtain the grey relational coefficients, the deviation sequences and the distinguishing coefficient were substituted in Equation 2.

In grey relation analysis, the maximum grade value represents the most influential factor that affect the output variable. In Table VI, the combination of A_1, B_1, C_3, and D_3 shows the largest value of the Grey relational grade for the factors A, B, C and D, respectively. Therefore, $A_1B_1C_3D_3$ with a feed rate of 1.5 mm/rev, a depth of cut of 0.3mm, annealed workpiece and pressurized steam jet of 4 kg/cm^2 was the optimal parameter combination for the surface grinding operation.

TABLE NO. VIII
ANOVA RESULTS FOR SN RATIOS FOR R_A

Source	DF	SS	MS	F	P
Feed rate(rev/mm)	1	21.30	21.297	8.50	0.013
Depth of cut(mm)	2	23.39	11.697	4.67	0.032
Pressurized Steam Jet (kg/cm^2)	2	24.60	12.299	4.91	0.028
Error	12	30.08	2.507		
Total	17	99.37			

TABLE NO. VII
SEQUENCES AFTER DATA PRE-PROCESSING FOR REFERENCE AND COMPARABILITY SEQUENCES

S. No.	Comparability Sequences				Reference sequences
	Feed Rate (mm)	Depth of Cut (mm)	Pressurized Steam Jet (kg/cm^2)	Surface Treatment Condition	Ra (µm)
1.	1.5	0.3	2	WHT	1.00
2.	1.5	0.3	3	HTHT	1.51
3.	1.5	0.3	4	AHT	0.77
4.	1.5	0.5	2	WHT	1.00
5.	1.5	0.5	3	HTHT	1.51
6.	1.5	0.5	4	AHT	1.51
7.	1.5	0.7	2	WHT	1.49
8.	1.5	0.7	3	HTHT	1.51
9.	1.5	0.7	4	AHT	1.51
10.	2	0.3	2	WHT	1.49
11.	2	0.3	3	HTHT	2.02
12.	2	0.3	4	AHT	1.02
13.	2	0.5	2	WHT	1.26
14.	2	0.5	3	HTHT	2.02
15.	2	0.5	4	AHT	1.51
16.	2	0.7	2	WHT	2.02
17.	2	0.7	3	HTHT	2.02
18.	2	0.7	4	AHT	1.77

According to Table VIII analysis of variance (ANOVA) for the R_a, the factor B i.e. depth of cut with 32% of contribution is the most significant controlled parameters followed by C i.e pressurized steam jet with contribution of 28% and A i.e feed rate with contribution of 13% for the surface grinding operation for the minimization of surface roughness.

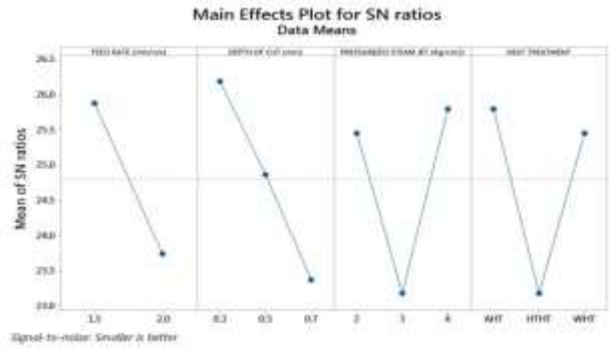

Figure 2. Main Effect Plot for SN ratios

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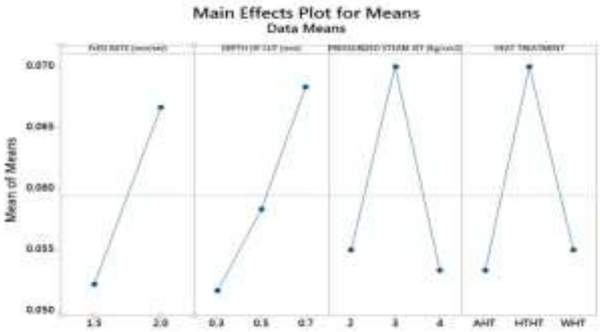

Figure 3. Main Effect Plot for Means

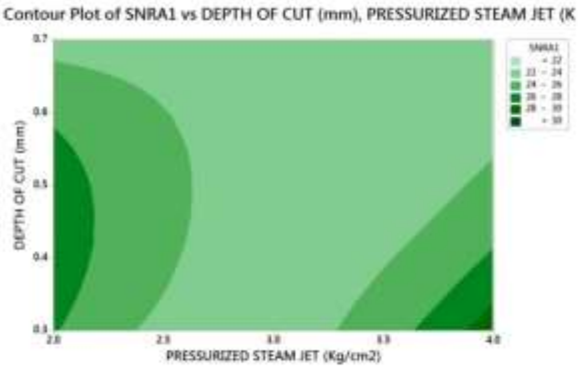

Figure 2. Contour Plot of SN Ratio vs Depth of Cut, Pressurized Steam Jet

III. Conclusion

In this study, a model to produce minimum surface roughness by pressurised steam jet was developed. This model was validated through experimental work.

1. As observed through ANOVA the significant parameters for minimum surface roughness was depth of cut followed by pressurized steam jet and feed rate.
2. The proposed model of pressurized steam jet was found to be one of the most effective parameters to minimize surface roughness.
3. The highest Grey relational grade of 1 was observed for the experimental run 3, shown in response table (Table No. VI) of the Grey relational grade, which indicates that the optimal combination of control factors and their levels are 0.3mm depth of cut, 4 kg/cm^2 pressurized steam jet, feed rate 1.5 mm/rev and annealing surface treatment condition.
4. The influence of annealing heat treatment on EN9 steel surface finish was higher than without heat treated material, while influence of hardening followed by tempering heat treatment was found to have negligible effect on surface finish.

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