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Use of Taguchi and Grey Relational Analysis Method to Optimize Multiple Responses of Drilling Process Parameters of EN36 Hardening Steel

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Abstract: **This research paper presents a novel methodology for optimizing the process parameters of drilling EN36, which is a nickel-chromium-molybdenum based case hardening engineering steel, using an orthogonal array and grey relational analysis that involves multiple responses. Carbide-coated HSS twist drills of different diameters are used for drilling under dry conditions. The study aims to optimize parameters such as spindle speed, feed rate, depth of cut and drill diameter while considering multiple responses, such as Surface Roughness and Material Removal Rate (MRR). Sixteen experimental tests were conducted based on L16 orthogonal Matrix. The grey relational analysis is employed to analyze the interdependence of parameters among multiple performance characteristics effectively. A grey relational grade is obtained from the analysis, which helps in identifying the optimum levels of parameters. The ANOVA is utilized to determine the significant contribution of parameters, while a confirmation test is conducted to validate the results. The findings indicate that the proposed approach effectively improves the drilling process responses.**

Keywords* — *ANOVA, Drilling, EN36, Grey relational analysis, L16 orthogonal matrix, Material Removal Rate, Optimizing, Orthogonal array, Process parameters, Surface roughness.

I. INTRODUCTION

EN36 is a hardening steel with high strength and toughness properties, primarily used in the manufacturing of heavy-duty components such as crankshafts and gears for aircraft and automotive industries. The steel contains chromium, nickel, and molybdenum as alloying elements, which contribute to its excellent hardenability and resistance to wear and fatigue. The hardening process involves heating the steel to a temperature between 820-860°C, followed by water or oil quenching and tempering at a lower temperature to achieve the desired hardness and ductility. EN36 steel is widely utilized in critical applications that require high strength, durability, and resistance to harsh operating conditions. Drilling on a CNC drilling machine involves the use of computer-controlled equipment to create precise holes in workpieces. The process typically involves selecting the appropriate drill bit, programming the machine to create the desired hole pattern, and then using the machine to drill the holes. CNC drilling machines offer a high level of accuracy and repeatability, making them suitable for a wide range of industrial applications.

Yang et al.,[1] used the Taguchi method to optimize cutting parameters for turning operations on S45C steel bars using tungsten carbide cutting tools. Deng and Chin et al.,[2] investigated the roundness of holes in BTA deep-hole drilling on AISI 1045 steel by Taguchi methods and found that feed rate, rotational speed, and tool diameter were strongly influential factors. Noorul Haq et al., [3] optimized drilling parameters for drilling Al/SiC metal matrix composite with multiple responses based on orthogonal

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array with grey relational analysis and identified the significant contribution of parameters by ANOVA. Palani kumar et al.,[4] found that feed rate was the dominant parameter affecting delamination in drilling of GFRP composites and suggested that feed rates should be lower to reduce delamination. Zhang and Chen et al.,[5] studied the effect of feed rate, spindle speed, peck rate, and tool type on surface roughness in CNC drilling of 1018 low carbon steel plates and found that tool type and spindle speed had a greater impact than feed rate, while work piece magnetism and vibration did not have significant impacts on surface roughness. Kilickap et al.,[6] investigated the optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite using Expert Systems with Applications and found that the best results for delamination were obtained at lower cutting speeds and feed rates. Kaladhar et al., [7] applied the Taguchi method and utility concept in solving the multi-objective problem when turning AISI 202 Austenitic Stainless Steel and found that feed had the most influence on the parameters followed by speed and depth of cut. Dhavamani et al.,[8] optimized machining parameters for aluminum and silicon carbide composite using Taguchi method, ANOVA, F-test Genetic Algorithm in CNC drilling machine and concluded that the application of multi-objective optimization based on Taguchi method increased the flexibility in selecting optimal cutting parameters for drilling process of composite materials.Pradeep Kumar et al.,[9] investigated the effect of drilling parameters on surface roughness, tool wear, material removal rate, and hole diameter error in drilling of OHNS in CNC drilling machine and found that feed and speed were important process parameters to control surface roughness, tool wear, material removal rate, and hole diameter error. Kadam Shirish et al.,[10] used the Taguchi method to optimize drilling parameters on EN-24 steel blocks workpiece for minimum surface roughness and maximum tool life and found that the use of high cutting speed, low feed rate, and low depth of hole led to better surface finish. Amran et al.,[11] studied the effects of machine parameters on aluminum alloy in CNC drilling machine using response surface method and found that the appropriate combination of spindle speed, feed rate, and drill diameter were important for drilling process.

These articles investigate the optimization of machining parameters for different materials and processes using the Taguchi method. Various input parameters such as cutting speed, feed rate, and tool diameter are optimized for multiple output responses like surface roughness, delamination, and tool wear. ANOVA and grey relational analysis are used to determine the significant contributions of input parameters on the output responses.

In this present paper, research is carried out to investigate multi response optimization drilling process parameters using CNC drilling machine on EN36 material by adopting Taguchy with Grey Relational analysis.

II. Experimental Setup & Procedure

A. Material Selection & Composition

The work piece material selected for machining on CNC machine for the present work is EN 36 Hardening Steel. EN 36 is 3% nickel, chromium, molybdenum grade. Carburised EN36 gives a hard case with a strong core, whilst retaining a remarkable degree of toughness. The chemical composition of EN36 is shown in Table 1.

Element	C	Mn	Si	Ni	Cr	S	P
Wt%	0.12-0.18	0.3-0.6	0.1-0.35	3-3.75	0.6-1.1	0.05	0.05

Table 1: Composition of EN36

For the workpiece selected, the proper drill bit is selected to predict process parameters. The basic composition of High Speed Steel is 18% tungsten (W), 4% Chromium (Cr), 1% vanadium (v), 0.7% carbon (C) and rest Iron (Fe).

B. Plan of Investigation

The factors and their levels considered in this study are shown in Table 2. Experiments are conducted with Orthogonal array which satisfies the required Dof is L16. The experiments are conducted using L16 OA and the factors combinations are given in Table 3 and their responses are shown in Table 4.

Parameter	**Units**	**Level-1**	**Level-2**	**Level-3**	**Level-4**
Spindle Speed (n)	rpm	1000	1500	2000	2500
Feed rate (fr)	mm/min	50	150	200	250
Depth of cut (d)	mm	6	8	12	15
Drill diameter (D)	mm	10	12	15	18

Table 2: Process parameters and their levels

III. Design of Experiments

In this study, a Taguchi-based grey relational analysis was conducted to optimize the drilling process parameters for achieving desired quality characteristics of surface roughness and MRR in EN36 hardening steel. The study involved a multi-response optimization problem, which was addressed using the following steps.

Step1: First, the Signal-to-Noise (S/N) ratios were calculated for the given response and predicted S/N ratios of the starting conditions depending upon the type of quality characteristic. The computed S/N ratios for each quality characteristic were shown in Table 5.

Step2: Next, the S/N ratio values were normalized and the results were given in Table 6.

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Step3: Grey relational analysis was then performed, and the grey relational coefficient for the normalized S/N ratio values was calculated. The results were given in Table 7.

Step4: The grey relational grade was computed based on the grey relational coefficient. The grades were then considered for optimizing the multi-response parameter design problem. The results were given in Table 8.

Step5: From the value of grey relational grade in Table 8, the main effects were tabulated in Table 9, and the factor effects were plotted in Fig. 1. Considering the maximization of grade values, the optimal parameter conditions D4B2C4A4 were obtained.

Step6: Using the grey grade value, Analysis of Variance (ANOVA) was formulated for identifying the significant factors. The results of ANOVA showed that depth of cut (61.47%) influenced drilling EN36 hardening steel the most, followed by drill diameter (26.36%), spindle speed (12.43%) and feed (2.64%). The results were given in Table 10.

Step7: To predict the optimum condition, the expected mean at the optimal settings (μ) was calculated, and the confirmation experiment was conducted at the optimal settings to verify the quality characteristics for drilling of EN36 by drilling process recommended by the investigation

The results showed that the grey relational analysis based on the Taguchi method was a useful tool for predicting the surface roughness and MRR in the drilling of EN36 hardening steel. The predicted optimum condition was confirmed by the confirmation experiment, which showed that the grey grade value was improved from the predicted mean value.

Exp.No	**SpindleSpeed**	**Feedrate**	**Depthof cut**	**DrillDia**
1	1000	50	6	10
2	1000	100	9	12
3	1000	150	12	15
4	1000	200	15	18
5	1500	50	9	15
6	1500	100	6	18
7	1500	150	15	10
8	1500	200	12	12
9	2000	50	12	18
10	2000	100	15	15
11	2000	150	6	12
12	2000	200	9	10
13	2500	50	15	12
14	2500	100	12	10
15	2500	150	9	18
16	2500	200	6	15

Table 3: L16 Orthogonal Array with Control Factors

Exp. No	**MRR mm^3/min**	**Average Surface roughness Ra (μm)**	**Root mean square roughness Rq (μm)**	**Ten point mean roughness Rz (μm)**
1	471	7.33	9.11	24.36
2	1017	4.97	6.03	18.32
3	2120	4.96	6.53	20.14
4	2200	3.93	4.83	14.15
5	1300	3.8	4.79	13.73
6	1526	5.13	5.99	17.23
7	1178	4.25	5.47	14.67
8	1200	4.89	5.94	18.04
9	3052	6.06	7.25	19.85
10	1900	3.76	4.93	14.97
11	678	7.25	8.61	24.00
12	707	6.39	7.64	20.50
13	1696	3.92	5.05	14.72
14	800	4.73	5.95	15.48
15	2000	3.9	4.89	12.90
16	1060	5.68	6.96	19.97

Table 4: Process Output Responses

Exp. No.	**MRR Mm^3/min**	**Average surface roughness Ra (μm)**	**Root mean square roughness Rq (μm)**	**Ten point mean roughness Rz (μm)**
1	0.0000	0.0000	0.0000	0.0000
2	0.2117	0.6611	0.7130	0.5271
3	0.6387	0.6639	0.5972	0.3682
4	0.6699	0.9524	0.9907	0.8909
5	0.3212	0.9888	1.0000	0.9276
6	0.4088	0.6162	0.7222	0.6222
7	0.2737	0.8627	0.8426	0.8455
8	0.2824	0.6835	0.7338	0.5515
9	1.0000	0.3557	0.4306	0.3935
10	0.5537	1.0000	0.9676	0.8914
11	0.0803	0.0224	0.1157	0.0314
12	0.0912	0.2633	0.3403	0.3368
13	0.4745	0.9522	0.9398	0.8412
14	0.1275	0.7283	0.7315	0.7749
15	0.5924	0.9608	0.9769	1.0000
16	0.2281	0.4622	0.4977	0.3831

Table 5: Signal to Noise Ratio Preprocessing Data

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Exp. No	MRR mm^3/min	Average Surface roughness Ra (µm)	Root mean square roughness Rq(µm	Ten point mean roughness Rz (µm)
1	1.0000	1.0000	1.0000	1.0000
2	0.7883	0.3389	0.2870	0.4729
3	0.3613	0.3361	0.4028	0.6318
4	0.3301	0.0476	0.0093	0.1091
5	0.6788	0.0112	0.0000	0.0724
6	0.5912	0.3838	0.2778	0.3778
7	0.7263	0.1373	0.1574	0.1545
8	0.7176	0.3165	0.2662	0.4485
9	0.0000	0.6443	0.5694	0.6065
10	0.4463	0.00000	0.0324	0.1806
11	0.9197	0.9776	0.8843	0.9686
12	0.9088	0.7367	0.6597	0.6632
13	0.5255	0.0448	0.0602	0.1588
14	0.8275	0.2717	0.2685	0.2251
15	0.4076	0.0392	0.0231	0.0000
16	0.7719	0.5378	0.5023	0.6169

Table 6: Normalisation values

Exp. No.	MRR Mm^3/min	Average surface roughness Ra (µm)	Root mean square roughness Rq (µm)	Ten point mean roughness Rz (µm)
1	0.333333	0.333333	0.333333	0.333333
2	0.388104	0.595993	0.635294	0.513901
3	0.580522	0.597990	0.553846	0.441789
4	0.602334	0.913043	0.981818	0.820917
5	0.424158	0.978082	1.000000	0.873476
6	0.458199	0.565769	0.642857	0.569583
7	0.407741	0.784615	0.760563	0.764000
8	0.410660	0.612350	0.652568	0.527139
9	1.000000	0.436965	0.467532	0.451893
10	0.528352	1.000000	0.939130	0.734615
11	0.352186	0.338389	0.361204	0.340463
12	0.354923	0.404304	0.431138	0.429857
13	0.487551	0.917738	0.892562	0.758940
14	0.36491	0.647913	0.650602	0.689531
15	0.550907	0.927273	0.955752	1.000000
16	0.393116	0.481781	0.498845	0.447656

Table 7: Grey Relational Coefficient

Experiment Number	Grey Relational Grade
1	0.333333
2	0.533323
3	0.543537
4	0.829528
5	0.818929
6	0.559102
7	0.679230
8	0.550679
9	0.589097
10	0.800524
11	0.348060
12	0.405055
13	0.764198
14	0.588084
15	0.858483
16	0.455350

Table 8: Grey Relational Grade

Parameters	Level	Level description	Units
Spindle Speed	A_4	2500	rpm
Feed	B_2	100	mm/min
Depth of cut	C_4	15	mm
Drill Diameter	D_4	18	mm

Table 9: Optimal Parameter Condition

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Spindle speed	3	0.05128	0.017094	2.26	0.260	12.43%
Feed	3	0.01079	0.003598	0.48	0.721	2.64%
Depth of cut	3	0.25293	0.084310	11.17	0.039	61.47%
Drill Diameter	3	0.10853	0.036178	4.79	0.115	26.36%
Error	3	0.02265	0.007550			
Total	15	0.44619				

Table 10: Significant Factors

IV. RESULTS AND DISCUSSIONS

1. Material Removal Rate (MRR)

a. Spindle Speed - 2500rpm

b. Feed rate - 150mm/min

c. Depth of Cut - 15mm

d. Drill Diameter - 18mm

2. Average surface roughness (Ra)

a. Spindle speed - 1500rpm

b. Feed rate -100mm/min

c. Depth of cut -15mm

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d. Drill diameter -15mm

3. **Root mean square roughness (Rq)**

a. Spindle speed - 1500rpm

b. Feed rate - 100mm/min

c. Depth of cut - 15mm

d. Drill Diameter - 18mm

4. **Ten point mean square roughness (Rz)**

a. Spindle speed - 2500rpm

b. Feed rate - 100mm/min

c. Depth of cut - 15mm

d. Drill Diameter -18mm

5. **MRR and surface roughness(Ra,Rq and Rz)**

a. Spindle speed - 2500rpm

b. Feed rate - 100mm/min

c. Depth of cut - 15mm

d. Drill diameter - 18mm

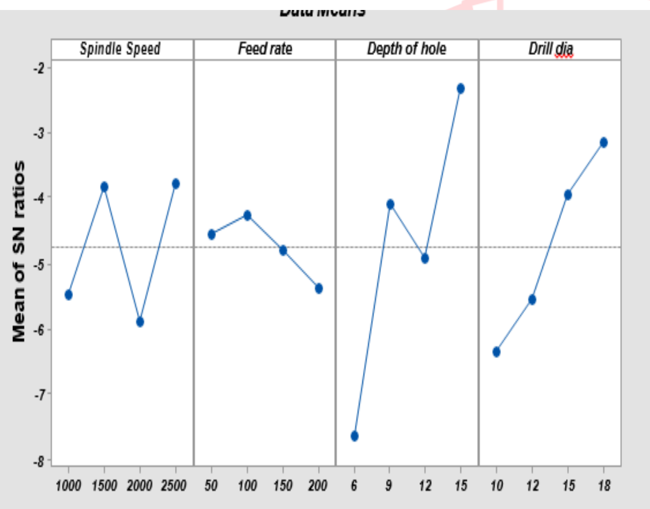

Fig1: Main Effects Plot

V. CONCLUSIONS

This study aimed to investigate the drilling performance of EN36 hardening steel using CNC drilling machine with a carbon coated HSS twist drill. Various drilling parameters were considered, and the resulting surface roughness and MRR values were recorded under different cutting conditions. Grey relational analysis in the Taguchi method was used to optimize the multi-response problems associated with drilling, and the prominent factors affecting the drilling process were identified. The analysis showed that the spindle speed, feed rate, depth of cut and drill diameters were the most significant factors, with the drill diameter having the greatest influence on the process. The study revealed that the optimum performance was achieved using a carbon coated HSS twist drill with a largest drill diameter of 18mm (D4), low feed of 100 mm/min (B2), higher depth of cut of 15mm(C4) and a higher spindle speed of 2500rpm(A4). The results of the confirmation test showed that this combination of drilling parameters satisfied the actual drilling requirements of EN36 steel. The study demonstrates the usefulness of grey relational analysis in the Taguchi method as a tool for predicting drilling performance and optimizing drilling parameters, without the need for complicated mathematical theories or statistical expertise.

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