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A Review on Multi Objective Optimization of Drilling Parameters Using Taguchi Methods

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Abstract -- **In this paper, a comprehensive and in-depth review on optimization of drilling parameters using Taguchi methods is carried out. The quality and productivity aspects are equally important in the analysis of drilling parameters. Taguchi methods are widely used for design of experiments and analysis of experimental data for optimization of processing conditions. The research contributions are classified into methodology for investigation and analysis, input processing conditions and response variables. It was observed that the optimal speed for a machine tool is influenced by several processing parameters such as hardness, composition, stiffness of work/tool and tool life. Furthermore, it is evident that surfaces finish necessary and power available significantly controls the feed. The roughness of drilled surfaces depends severely on the input conditions, material of the workpiece or tool and condition of the machine tool. The grey relational analysis is the most accurate and effective tool for analysis of data for a CNC drilling process. This study has indicated that Taguchi method followed by grey relational analysis is the most efficient combination for the following: design of experiments, analysis of experimental data and for the subsequent multi-objective optimization in drilling process.**

Keywords: Drilling Parameter, Response Variable, Optimization, Taguchi Orthogonal Array, Grey Relational Analysis and Surface Quality.

I. INTRODUCTION

DRILLING can be described as a process where a multi-point tool is used to remove unwanted materials to produce a desired hole. It broadly covers those methods used for producing cylindrical holes in the work piece. Hole making had long been recognized as the most prominent machining process, requiring specialized techniques to achieve optimum cutting condition.The Drilling machines are highly used in an industry for metal removal operation. It is therefore, essential to optimize quality and productivity simultaneously [1-4]. Productivity can be interpreted in terms of material removal rate in the machining operation and quality represents satisfactory yield in terms of product characteristics as desired by the customers. There are number of research papers related to drilling, reaming and boring. In most of these research works carried out, material removal rate (MRR) and surface roughness are selected as objective functions [5-7]. Furthermore, optimum values for input parameters such as speed, feed, different cooling condition are calculated to obtain maximum MRR and minimum surface roughness value. The other aspect governing drilling systems is quality of design. The quality of design can be improved through improving the value and yield in company-wide activities [8]. Quality and productivity are two important parameters having an inter-connection with each other. The designs of experiments are also significant in optimization. Among all the experimental design techniques, Taguchi methods are widely applied for optimizing machining operations having more than one objective [9-12]. It is therefore evident that in any machining operation, Taguchi parameter design offers a systematic method for optimization techniques of various parameters with the regarding to performance quality and cost.

The metal cutting process involves plastic deformation, fracture, impact continuous and intermittent multi contact points and friction. Direct visual inspection is never possible since workpiece and chip obstruct the view therefore sensors are used to observe the failure [13-16]. To get desired quality cutting parameters should be selected in a proper way. It has been reported that drilling is a complex operation when compared to other machining operation as the two points of the drill wear alternately till they both have zero clearance at the margin, and become lodged within work piece [17]. The main factors affecting the hole quality i.e. cutting speed, temperature, feed rate, geometrical parameters as well as the influence of the cutting conditions and the temperature on the tool life in drilling was studied in another investigation [18]. They suggested that improvement of surface quality and dimensional accuracy of the holes can be got at large cutting speed and a weak feed rate.

Many researchers have used Taguchi methods for their design experiments. Taguchi method systematically reveals the complex cause and effect relationship between design parameter and performance. Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to statistical process control which attempt to control the factors that adversely affect the quality of production [3, 19]. There has been research on the quality of the holes drilled during research as well. Surface roughness is a major matter of concern over the last few years as industries desperately try to excel in quality and reduce the price simultaneously [10]. It is indicated as an important design feature in many situations such as parts subject to fatigue loads, precision fits, and aesthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning.

II. CLASSIFICATION OF RESEARCH WORKS

The contributions by various researchers on optimization of drilling parameters using Taguchi methods can be classified. This classification is simplified and presented in Fig. 1. The research works are classified under the following:

1. The methodology for performing the investigation
2. The method for analysis
3. The input processing conditions/parameters for the simulation/modeling/experimentation
4. The outputs of the process or response variables
5.

of the factors on the process response has been deduced by using ANOVA method.

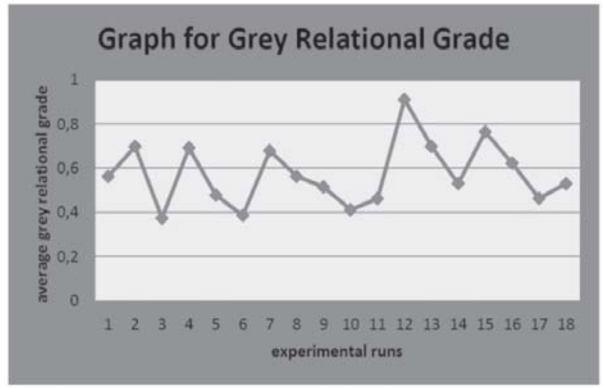

Figure 2. The plot average grey relational grade v/s experimental runs for CNC drilling [1].

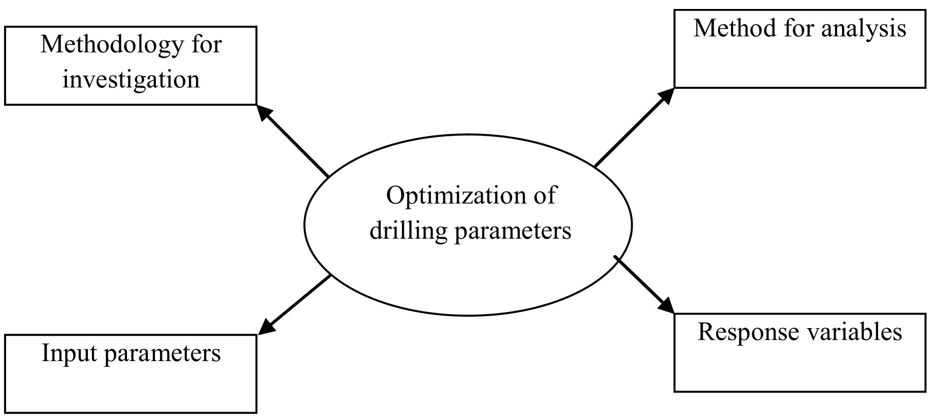

Figure 1. Theme of classification of research works on optimization of drilling parameters.

Based on the theme presented in Fig. 1, the literatures on optimization of drilling parameters are discussed in detail, covering all aspects:

Considering the methodology for experimentation and analysis, standardized methods were suggested by DOE for each of steps which have been used comprehensively in all these works to significantly reduce the number of experiments and form the rule box. Several input parameters and different rules have been taken depending upon standard orthogonal arrays based on Taguchi Design. The degree of significance of each

In the study conducted by Reddy Sreenivasalu and Dr. Ch Srinivasa Rao [1], the effect of drilling parameters on surface roughness and roundness error were investigated in drilling of Al6061 alloy with HSS twist drill. Optimal control factors for hole quality were determined using Taguchi grey relational analysis. Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio were considered as the control factors. L_{18} orthogonal array was determined for experimental trials. Grey relational analysis was employed to minimize surface roughness and roundness error. The factors and their levels for the experiment are shown in Table 1.

TABLE 1- FACTORS AND LEVELS OF EXPERIMENT [1]

Levels of Experimental factors	Cutting speed, v (mm/min)	Feed rate, f (mm/rev)	Drill diameter, d (mm)	Point angle, β (°)	Cutting fluid mixture ratio, k (%)
1	15.08	0.3	8	118	12
2	25.13	0.5	10	110	18
3	37.70	0.6	12	100	24

This work has indicated that the order of the importance of influential factors based on the Taguchi response in sequence is point angle, drill diameter, feed rate, %cutting fluid mixture ratio and cutting speed. Fig. 2 shows the relationship between average grey relational grade and experimental runs for the CNC drilling operations. It is evident that the grey relational grade fluctuates between 0.4 and 0.9. The graph between grey relational grade and individual drilling parameters are shown in Fig. 3 *a-e*.

In another similar work,Dinesh Kumar, L.P.Singh, GagandeepSingh[2], described the Taguchi technique for optimization of surface roughness in drilling process. In their investigation, Taguchi technique was used as one of the method for minimizing the surface roughness in drilling mild steel. The Taguchi method is a powerful tool to design optimization for quality, was used to find optimal cutting parameters. The methodology is useful for modeling and analyzing engineering problems.

The purpose of this study is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on surface roughness produced when drilling Mild steel. A plan of experiments, based on detailed L27 Taguchi

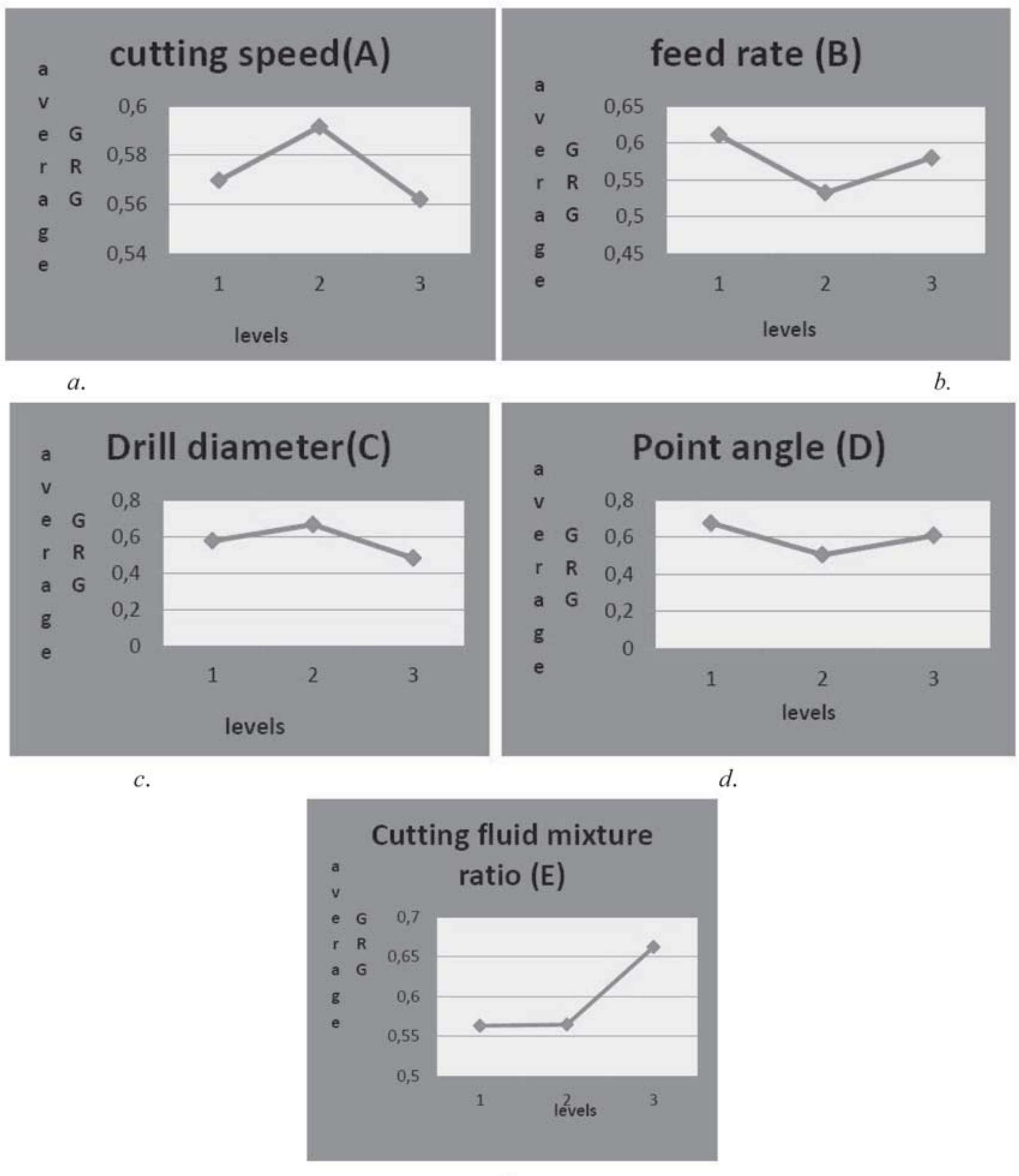

Figure 3. *a-e*: Graphs of grey relational grade forindividual drilling parameters [1].

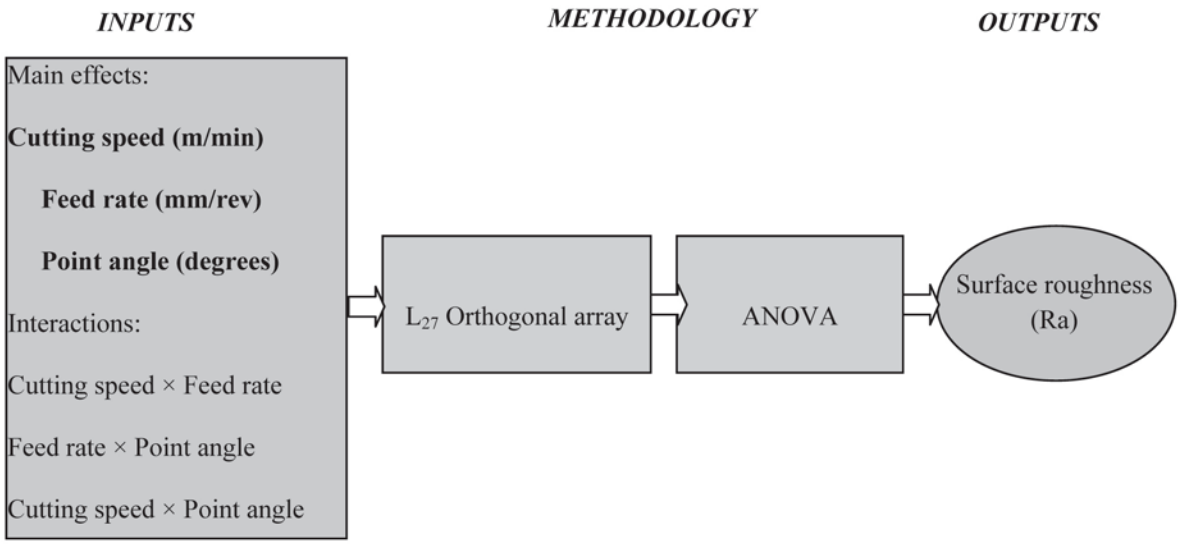

Figure 4. Flow diagram of methodology for analysis of surface roughness (Ra) in drilling [2].

design method, was performed drilling with cutting parameters in Mild steel (see Fig. 4). The orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters of Mild steel. From the analysis of means and ANOVA, the optimal combination levels and the significant drilling parameters on surface roughness were obtained. The optimization results showed that the combination of low cutting speed, low feed rate, and medium point angle is necessary to minimize surface roughness.

The effect of parameters such as Cutting speed, feed rate and point angle and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Surface roughness, see Fig. 2. Some results consolidated from ANOVA and plots are given below:

TABLE 2 --DRILLING PARAMETERS AND THEIR LEVELS [2].

Levels of Experimental factors	Cutting speed (mm/min)	Feed rate (mm/rev)	Point angle (°)
1	7	0.035	90
2	18	0.07	140
3	30	0.14	118

After the analysis of the results in ANOVA table, cutting speed is found to be the most significant factor (F-value 15.16655) & its contribution to Surface roughness is 26.16802% followed by feed rate (F-value 13.46045) the factor that significantly affected the surface roughness which had contribution of 23.06687% respectively. The interaction between feed rate and point angle (F-value 5.004773) is found to be significant which contributes 15.39427% and the interaction between point angle and cutting speed (F-value 5.493636) is found to be significant which contributes 17.17147%. The following conclusions have been drawn from the study:

1. Surface roughness is mainly affected by cutting speed and feed rate as per the main effects plot for SR. Surface Roughness is higher with the increase in cutting speed and feed rate when the experimentation is done.
2. From ANOVA analysis, parameters making significant effect on surface roughness feed rate, was found to be significant for reducing the variation followed by cutting speed respectively.

The AOM results are presented in Fig. 5.

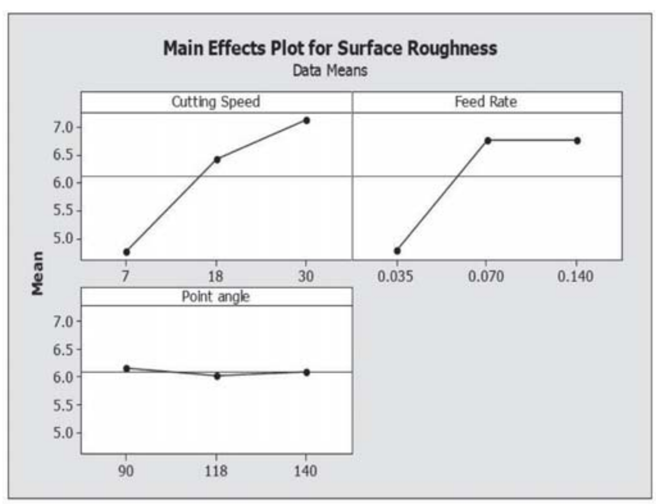

Figure 5. AOM plots indicating the effect of drilling parameters on surface roughness [2].

The work by Tyagi *et al.* [3] reported the drilling of mild steel with the help of CNC drilling machine operation with tool as high speed steel by applying Taguchi methodology. The Taguchi method is applied to formulate the experimental layout to ascertain the Element of impact each optimum process parameters for CNC drilling machining with drilling operation of mild steel.

TABLE 3 -- PARAMETERS AND THEIR LEVELS FOR THE DRILLING PROCESS [3].

Levels of Experimental factors	spindle speeds	Feed rate	Depth of cut (mm)	Response variables
1	1000	0.5	3	1.Material removal rate
2	1500	1.0	5	2.Surface roughness
3	2000	1.5	7	

A L_9 array, Taguchi method and analysis of variance (ANOVA) are used to formulate the procedure tried on the change of parameter layout. The available material study in focuses optimization of CNC Drilling machine process parameters (Fig. 6) to provide good surface finish as well as high material removal rate (MRR). The surface finishing and material removal rate have been identified us quality attribute and are assumed to be directly related to productivity. The selection of optimal machining parameters i.e., spindle speed, depth of cut and feed rate) for drilling machine operations was investigated in order to minimize the surface roughness and to maximize the material removal rate, see Figures 7 and 8.

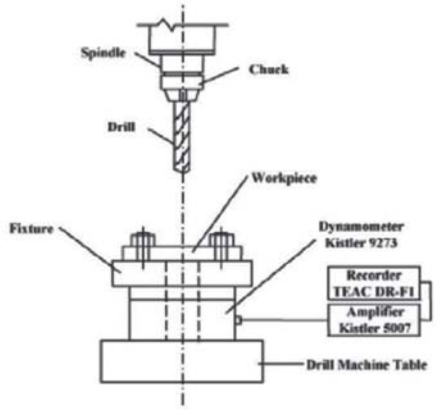

Figure 6. Line diagram of experimental set-up [3].

The following conclusions are obtained from this study,

- The Spindle Speed of drilling machine Tool mainly affects the SR.
- The Feed Rate largely affects the MRR.

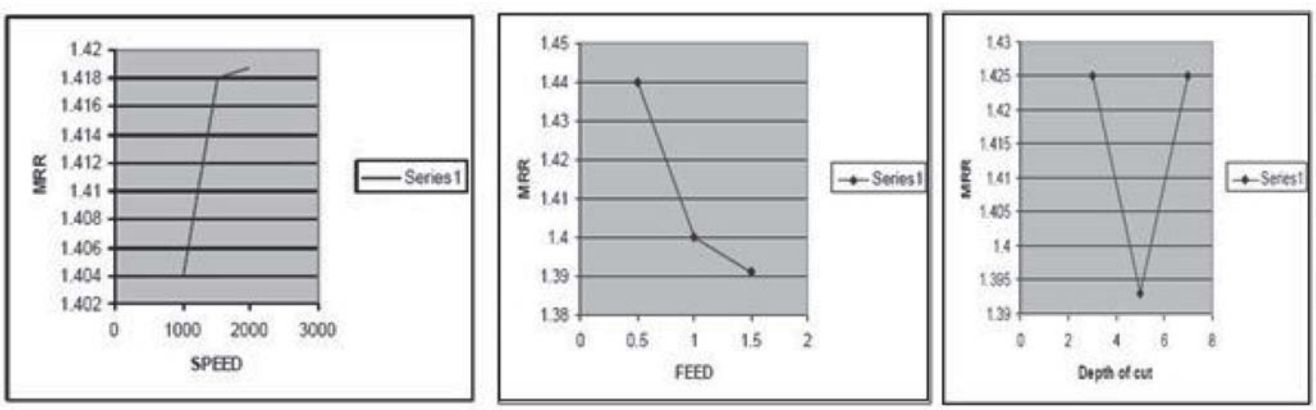

Figure 7. Effects of parameters on MRR [3].

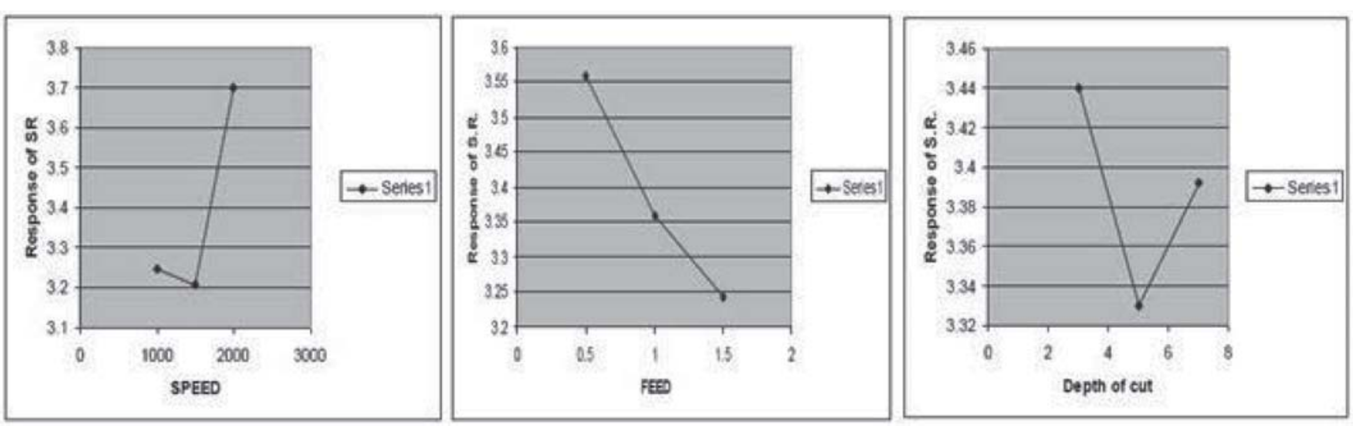

Figure 8. Effects of parameters on surface roughness [3].

In the study conducted by Jindal and Singla [4], the Taguchi optimization methodology is applied to optimize cutting parameters in drilling of glass fiber reinforced composite (GFRC) material. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. This procedure eliminates the need for repeated experiments, time and conserves the material by the conventional procedure. The drilling parameters and specimen parameters evaluated are speed, feed rate, drill size and specimen thickness. A series of experiments are conducted using Radial Drilling Machine to relate the cutting parameters and material parameters on the cutting thrust and torque. The measured results were collected and analyzed with the help of the commercial software packageMINITAB 15. An orthogonal array, signal-to-noise ratio are employed to analyze their influence of these parameters on cutting force and torque during drilling.The following conclusions were obtained from this study.

- From the analysis of result in the drilling using conceptual S/N ratio approach, Taguchi method provides a simple, systematic and efficient methodology for the optimization of the process parameters and this approach can be adopted rather than using engineering judgment.
- The multiple performance characteristics such as tool life, cutting force, surface roughness and the overall productivity can be improved by useful tool of Taguchi method.
- It is observed that specimen thickness, feed rate, speed and diameter are significant parameters of cutting thrust.

Shivapragash *et al.* [5] focused on multiple response optimization of drilling process for composite Al-TiBr2. The study provided to minimize the damage events occurring during drilling process for composite material. A statistical approach used to analyze experiment data. Taguchi method with grey relational analysis was used to optimize the machining parameters with multiple performance characteristics in drilling of MMC Al-TiBr2. The results shows that the maximum feed rate, low spindle speed are the most significant factors which affect the drilling process and the performance in the drilling process can be effectively improved by using this approach.

TABLE 4 -- DRILLING PARAMETERS AND LEVELS [5].

Levels of Experimental factors	spindle speeds	Feed rate	Depth of cut (mm)	Response variables
1	1000	0.5	2	1.Material removal rate 2.Surface roughness
2	1500	1.0	4	
3	2000	1.5	6	

The optimum drilling parameters obtained from the grey relational grade value. The obtained grey relational grades for each parameter are presented in the Table 5.

Following conclusions can be drawn:

- Optimum cutting parameters for minimization surface roughness is spindle speed set as low level (1000 rpm), feed rate set as maximum level (1.5 mm/min) and depth of cut set as middle level (6 mm).
- Optimum cutting parameters for maximization material removal rate is spindle speed set as low level (1000 rpm), feed rate set as maximum level (1.5 mm/min) and depth of cut set as middle level (6 mm).

TABLE 5 -- OPTIMUM LEVEL OF DRILLING PARAMETERS [5].

Factors	1	2	3
Spindle speed	**0.701696**	0.47653	0.472823
Feed rate	0.427704	0.588836	**0.634508**
Depth of cut	0.470891	**0.657969**	0.522188

The investigation by Ali Riza Motorcu [6],the surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was investigated in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool nose radius, using a statistical approach (see Table 6). Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness.

TABLE 6 -- FACTORS AND THEIR LEVELS FOR DRILLING PROCESS [6].

Factors	**Level1**	**Level 2**
Cutting speed (m/min)	150	210
Feed rate (mm/rev)	0.11	0.24
Depth of cut (mm)	0.3	1
Tool nose radius (mm)	0.8	1.2

The obtained results indicate that the feed rate was found to be the dominant factor among controllable factors on the surface roughness, followed by depth of cut and tool's nose radius. However, the cutting speed showed an insignificant effect. Furthermore, the interaction of feed rate/depth of cut was found to be significant on the surface finish due to surface hardening of steel. Optimal testing parameters for surface roughness could be calculated.

The following conclusions may be drawn from various cutting conditions in machining the hardened AISI 8660 steels by ceramic cutting tools. Feed rate exerted the greatest effect on surface roughness, followed by depth of cut. The surface roughness increased with increasing feed rate, depth of cut and decreased with increasing the tool's nose radius. The cutting speed had no significant effect on the tested materials.

TABLE 7 -- DRILLING PARAMETERS FOR THE PROCESS [7].

Cutting Parameter	Level 1	Level 2
Cutting tool	CHT	CT
Cutting speed	12	14
Feed rate	0.08	0.1
CHT- Conventionally heat treated *CT - Cryogenically treated*		

In the work done by AdemÇiçek *et al.* [7], the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, optimal control factors for the hole quality were determined by using Taguchi technique. Two cutting tools, cutting speeds and feed rates were considered as control factors, and L8(23) orthogonal array was determined for experimental trials, see Table 7 for the input parameters.

In the performed experimental trials using Taguchi orthogonal arrays, it was found that the cutting speed (78.11%) had a significant effect on the surface roughness and that the cutting speed (35.352%) and feed rate (35.352%) had significant effects on the roundness error. The quality losses (52.36%) of the surface roughness obtained at optimal combinations (Ct = CT, V = 14 m/min, f= 0.08 mm/rev) were nearly equal to half of the ones obtained from experimental combinations. Similarly, the quality losses of the roundness error obtained at optimal combinations became 51.76%. Optimal surface roughness and roundness error values were calculated as 1.77 µm and 5.60 µm using optimal parameters, respectively.

Show-Shyan Lin *et al.* [8], investigated the optimization of computer numerical control (CNC) boring operation parameters for aluminum alloy 6061T6 using the grey relational analysis (GRA) method. Nine experimental runs based on an orthogonal array of Taguchi method were performed. The surface properties of roughness average and roughness maximum as well as the roundness were selected as the quality targets. An optimal parameter combination of the CNC boring operation was obtained via GRA. By analyzing the grey relational grade matrix, the degree of influenced for each controllable process factor onto individual quality targets can be found.

- The feed rate is identified to be the most influence on the roughness average and roughness maximum and the cutting speed is the most influential factor to the roundness.
- The analysis of variance (ANOVA) was also applied to identify the most significant factor; the feed rate is the most significant controlled factor for the CNC boring operations according to the weighted sum grade of the roughness average, roughness maximum and roundness.

A summary of the review based on the methodology is presented in Table 8. It is evident that material removal rate, surface roughness and roundness error were analyzed in most of the cases. The processing parameters and response variables are discussed in detail, in the following sections.

TABLE 8 -- SUMMARY OF THE REVIEW BASED ON THE METHODOLOGY

1	Application of grey relational analysis for surface roughness and roundness error in drilling of Al 6061 alloy	Reddy Sreenivasalu DrCh.SreenivasaRao	Cutting speed , Feed rate, Drill diameter , Point angle, Cutting fluid mixture ratio.	Surface roughness Roundness error
2	Operational Modeling For Optimizing Surface roughness In Mild Steel Drilling Using Taguchi Technique.	Dinesh Kumar, L.P.Singh, Gagandeep Singh	Cutting speeds Feed rate Point angle	Surface roughness
3	Parametric Optimization of Drilling Machining Process using Taguchi Design and ANOVA Approach	YogendraTyagi, VedanshChaturvedi, JyotiVimal	spindle speeds Feed rate Depth of cut	Material removal rate, Surface roughness
4	Experimental Investigation of Process Parameters in drilling operation using different software technique	Anil Jindal, Dr. V. K. Singla	speed, feed rate, drill size, specimen thickness	cutting thrust torque
5	Multiple Response Optimizations in Drilling Using Taguchi and Grey Relational Analysis.	B.Shivapragash, K.Chandrasekaran, C.Parthasarathy, M.Samuel	spindle speed Feed rate Depth of cut	Material removal rate Surface roughness
6	The Optimization of Machining Parameters Using the Taguchi Method for Surface Roughness of AISI 8660 Hardened Alloy Steel	Ali RizaMotorcu	Cutting speed Feed rate Depth of cut Tool nose radius	Surface roughness
7	Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel	AdemÇiçek, TurgayKıvak, GurcanSamtaş	Cutting tool Cutting speed Feed rate	Surface roughness Roundness error
8	Optimization of 6061T6 CNC Boring Process Using the Taguchi Method and Grey Relational Analysisby	Show-Shyan Lin, Ming-Tsan Chuang, Jeong-Lian Wen, Yung Kuang Yang	Feed Rate Cutting Speed	Surface roughness Roundness error
9	Experimental Analysis On Surface Roughness Of CNC End Milling Process Using Taguchi Design Method	Patel K. P	Tool Speed, Tool Feed, Depth Of Cut Tool Diameter	Surface roughness

III. INPUT PARAMETERS

Drilling speed: The speed of a drill is usually measured in terms of the rate at which the outside or periphery of the tool moves in relation to the work being drilled. The peripheral and rotational velocities of the tool are related as shown in the following equation:

$$V = \pi * D * N \quad (1)$$

where,
V is the recommended peripheral velocity for the tool being used, D is the diameter of the tool and N is the rotational velocity of the tool.

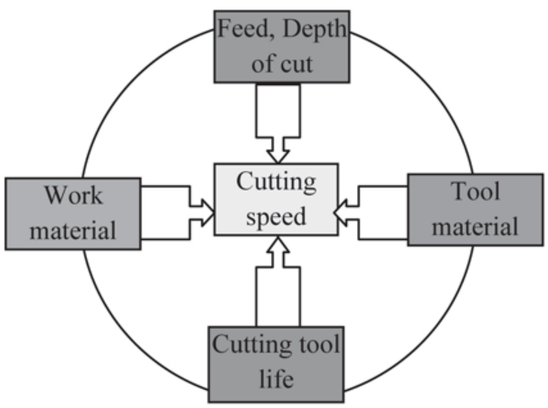

Figure 9. The factors significantly influencing cutting speed.

The cutting speed to be used depends on the factors, as presented in Fig. 9. The optimum speed for a particular set-up is affected by many factors, including the following:

- Composition, hardness & thermal conductivity (k) of material
- Depth of hole
- Efficiency of cutting fluid
- Type, condition and stiffness of drilling machine
- Stiffness of workpiece, fixture and tooling (shorter is better)
- Quality of holes desired
- Life of tool before regrind or replacement

Feed rate: It may be defined as the relatively small movement per cycle of the cutting tool [9], relative to the workpiece in a direction usually perpendicular to the cutting speed direction. It is expressed in millimeter per revolutions (mm/rev), or millimeter per stroke (mm/stroke).In turning and drilling, the feed is the axial advance of the tool along or through the job during each revolution of each tool or job. In case of shaper and planer, it is the lateral offset between the tool and work for each stroke. For multi tooth milling cutters, it is the advance of work or cutter between the cutting actions of two successive teeth. Feed to be used depending on the following factors: Smoothness or finish required, power available, condition of machine and its drive, type of cut and tool life, see Fig. 10.

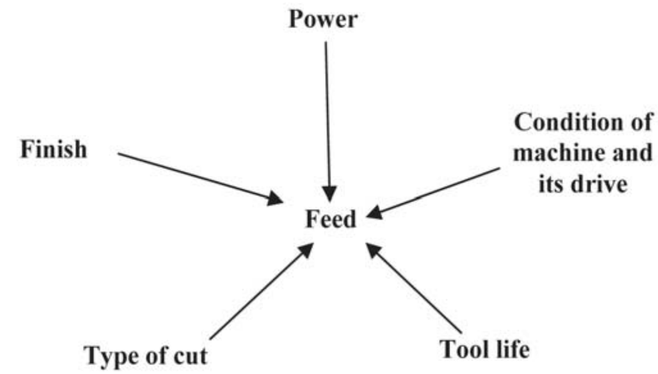

Figure 10 Dependence of feed on other parameters.

Coolants: In all metal working operations in workshops the use of metal working fluids are very essential. These fluids are given various names viz coolants, lubricants, and cutting compounds or cutting fluids according to their use. The metal working fluids usually perform following functions:

- Increase the tool life and produce better surface finish
- Minimize the friction between mating surface and thus prevents rise in temperature.
- Provide lubrication at higher pressure.
- Drive away chips scale and dirt etc

IV. RESPONSE VARIABLES

4.1 Material removal rate (MRR): The material removal rate (MRR) in drilling is the volume of material removed by the drill per unit time. For a drill with a diameter D, the cross-sectional area of the drilled hole is$\pi D^2/4$.The velocity of the drill perpendicular to the workpieceis the product of the feed $f$and therotational speed Nwhere $N = V/\pi D$.Thus,

$$MRR = (\pi D^2 / 4)\,(f)\ \text{mm}^3/\text{min} \quad (2)$$

Surface roughness: The concept of roughness is often described with terms such as 'uneven', 'irregular', 'coarse in texture', 'broken by prominences', and other similar ones [14]. Similar to some surface properties such as hardness, the value of surface roughness depends on the scale of measurement. In addition, the concept roughness has statistical implications as it considers factors such as sample size and sampling interval. The characterization of surface roughness can be done in two principal planes [14]. Using a sinusoidal curve as a simplified model of the surface profile, roughness can be measured at right angles to the surface in terms of the wave amplitude, and parallel to the surface in terms of the surface wavelength. The latter one is also recognized as texture. The technique used to measure roughness in any of these two planes will inevitably have certain limitations. The smallest amplitude and wavelength that the instrument can detect correspond to its vertical and horizontal resolution, respectively. Similarly, the largest amplitude and wavelength that can be measured by the instrument are the vertical and horizontal range.

Out of all the surface condition criteria, Ra and Rt(expressed in µm) are often used to characterize the roughness of machined surfaces. Rtis total roughness (maximum depth or amplitude of the roughness), and Ra is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness) as given in

$$Ra = (\Sigma A + \Sigma B)/L \quad (3)$$

Definition of the mean line is $\Sigma A = \Sigma B$ is shown in Fig. 11. Surface condition is by determined by several factors:

- Cutting parameters (cutting speed, feed)
- Tool geometry (angle and sharpness of the cutting edge, corner radius, etc)
- The material of the cutting tool is made from the rigidity of the assembly and of the machine,
- The forming of chips, cutting forces, etc.

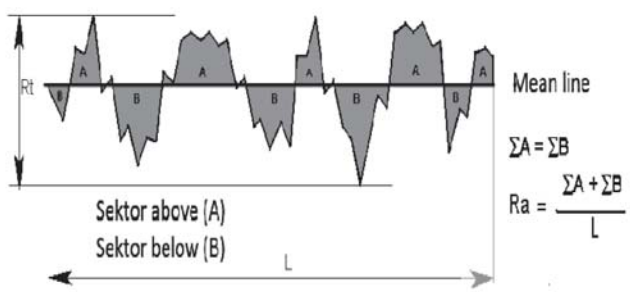

Figure 11. Definition of the mean line in evaluation of surface roughness.

V. RESEARCH METHODOLOGY

Grey relational analysis: In grey relational analysis, black represents having no information and white represents having all information. A grey system has level of information between black and white. This analysis can be used to represent the grade of co relation between two sequences so that distance of two factors can be measured discretely. In the case when experiments are ambiguous or when experimental method cannot be carried out exactly, grey analysis help to compensate for the shortcomings in statistical regression.

Grey relational analysis was proposed by Deng in 1989 as cited in is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade [11]. The use of Taguchi method with grey relational analysis to optimize the drilling process with multiple performance characteristics includes the following steps:

1. Identify the performance characteristics and cutting parameters to be evaluated.
2. Determine the number of levels for the process parameters.
3. Select the appropriate orthogonal array and assign the cutting parameters to the orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Normalize the experiment results of cutting force, tool life and surface roughness.
6. Perform the grey relational generating and calculate the grey relational coefficient.
7. Calculate the grey relational grade by averaging the grey relational coefficient.
8. Analyze the experimental results using the grey relational grade and statistical ANOVA.
9. Select the optimal levels of cutting parameters.
10. Verify the optimal cutting parameters through the confirmation experiment.

Data Pre-Processing: In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data. The original reference sequence and pre-processed data (comparability sequence) are represented by *xx0(0)(kk) and xxii(0)(kk), i =1,2,......, n* respectively, where m is the number of experiments and n is the total number of observations of data. Depending upon the quality characteristics, the three main categories for normalizing theoriginal sequence are identified as follows:

If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger-the-best':

$$X_i^*(k) = [\max X_i^{(0)}(k) - X_i^{(0)}(k)] / [\max X_i^{(0)}(k) - \min X_i^{(0)}(k)] \quad (4)$$

If the original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'smaller-the best':

$$X_i^*(k) = [X_i^{(0)}(k) - \min X_i^{(0)}(k)] / [\max X_i^{(0)}(k) - \min X_i^{(0)}(k)] \quad (5)$$

However, if the original data has a target optimum value (OV) then quality characteristic is 'nominal-the-better' and the original data is pre-processed as 'nominal-the-better'.

$$X_i^*(k) = 1 - \{|X_i^{(0)}(k) - OV| / \max[\max X_i^{(0)}(k) - OV, OV - \min X_i^{(0)}(k)]\} \quad (6)$$

Also, the original sequence is normalized by a simple method in which all the values of the sequence are divided by the first value of the sequence.

$$X_i^*(k) = X_i^{(0)}(k) / X_i^{(0)}(1) \quad (7)$$

Grey Relation Grade: Next step is the calculation of deviation sequence, Δ i ( ) from the reference sequence of pre-processes data $X_i^*(k)$ and the comparability sequence $X_i^*(k)$. The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$\gamma(X_0^*(k), X_i^*(k)) = (\Delta min + \Delta max)/ (\Delta 0i(k) + \Delta\ max) \quad (8)$$

$$0<\gamma (X_0^*(k), X_i^*(k)) <1$$

where,
$\Delta 0i(k)$ is the deviation sequence of the reference sequence $Xi^*(k)$and comparability sequence $Xi^*(k)$.

$$\Delta 0i(k) = |X0^*(k)- Xi^*(k)| \quad (9)$$

$$\Delta max = \underset{\forall j \in i}{max} \underset{\forall k}{max} |x_0^*(k) - x_i^*(k)| ; \quad (10)$$

$$\Delta min = \underset{\forall j \in i}{min} \underset{\forall k}{min} |x_0^*(k) - x_i^*(k)| \quad (11)$$

where ξ is the distinguishing coefficient ξ∈[0,1]. The distinguishing coefficient (ξ) value is chosen to be 0.5. A grey relational grade is the weighted average of the grey relational coefficient and is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta k \gamma\big((x_0^*(k), x_i^*(k)\big), \sum_{k=1}^{n} \beta k = 1 \quad (12)$$

The grey relational grade $\gamma (X_0^*, X_i^*)$ represents the degree of correlation between the reference and comparability sequences. If two sequences are identical, then grey relational grade value equals unity. The grey relational grade implies that the degree of influence related between the comparability sequence and the reference sequence. In case, if a particular comparability sequence has more influence on the reference sequence than the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other grey relational grades. Hence, grey relational grade is an accurate measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

VI. CONCLUSION

The following conclusions can be drawn from this in-depth literature review on CNC drilling processes:

- Taguchi method has been used to determine the main effects, significant factors and optimum machining conditions to obtain better performance characteristics.
- The multiple performance characteristics such as tool life, cutting force, surface roughness and the overall productivity can be improved by useful tool of Taguchi method.
- The optimum speed for a particular setup is affected by many factors, including Composition, hardness & thermal conductivity (k) of material, Depth of hole Efficiency of cutting fluid type, condition and stiffness of drilling machines, Stiffness of workpiece, fixture and tooling (shorter is better) Quality of holes desired, Life of tool before regrind or replacement.
- Feed to be used depending on the following factors, finish required, Power available, Condition of machine and its drive etc.
- Surface roughness is determined by several factors which include cutting parameters such as cutting speed, feed, depth of cut, Tool geometry, The material of the cutting tool, Machining condition etc.
- Grey relational analysis is widely used for measuring the degree of relationship between sequences by grey relational grade.
- Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade.

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