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INVESTIGATION ON THE EFFECT OF DRILLING PROCESS PARAMETERS ON SURFACE-ROUGHNESS

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Abstract— Present paper investigates the effect and optimization of process parameters (spindle speed, vertical feed rate and drill diameter) on surface roughness of High Carbon and High chromium (HCHCr) steel in drilling operation. Three carbide drills having diameters of 8mm, 10mm, 12mm are used. Nine experimental runs were performed as per Taguchi's L9 orthogonal array. Signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were employed to analyze the effect of drilling parameters on surface roughness of the drilled holes. Results revealed that the spindle speed was the dominant factor affecting surface roughness. Further, optimization of process parameter revealed that $A_3B_1C_3$ (spindle speed (A) of 3000 rpm, vertical feed rate (B) of 5 mm/min and drilling diameter (C) of 12 mm) is found to be optimized parameter combination for getting minimum surface roughness. Confirmation test results showed that the Taguchi method was very successful in the optimization of drilling parameters for minimizing surface roughness.

Keywords — Drilling, surface roughness, Taguchi method, optimization; HCHCr steel.

1 INTRODUCTION

Drilling is a process of producing round holes in a solid material or enlarging existing holes with the use of multi-point rotating tools called drills or drill bits. Drilling is a continuous machining process. Various cutting tools are available for drilling, but the most common is the twist drill. Wide variety of drill processes are available to serve different purposes (core drilling, step drilling, counter boring, counter sinking, reaming, center drilling, gun drilling etc.). It was reported that, in aircraft industry, the rejection of parts consist of composite laminates due to drilling-induced delamination damages during final assembly was as high as 60%. Defu et al. [1] mentioned that amongst all machining operations, drilling using twist drill is the most commonly applied method for generating holes. A low (<1000 Hz) or high (>1000 Hz) frequency and low amplitude vibration if superimposed on a twist drill bit along the vertical feed direction during drilling could reduce the delimitation.

The surface quality of hole-depth is the main problem associated with deep drilling of machined components. Surface roughness is a combination of finer irregularities over machined surfaces due to inherent action of the production process. Surface roughness has received great influence on functioning of machined parts which significantly improves creep life, fatigue strength and corrosion resistance. Surface roughness of industrial components strongly affects their performance, i.e. noise made during work, reflectivity, maintenance and cost of service. Nowadays its importance is soaring indeed, as the size of the manufactured elements has been reduced to micrometers or even nanometers. As a result, it is not surprising at all that paramount significance is attached to surface texture measurements, too.

HCHCr steel is cold work steel with high carbon high chromium contents. The most important quality of this steel is its high wear resistant and due to addition of vanadium. HCHCr tool steel is widely applicable for cold stamping or forming dies, cold forming rolls, Chipper knives, Punches, slitters, shear blades, tools, tyre shredders, trimming, cutting Threading Dies, stamping tools etc.

Literature survey reveals that twist drills have been the subject of numerous investigations because of their importance in nearly all production operations. Gillespie [2] observed that the cost of deburring and edge finishing on precision component may contribute as much as 30% to the cost of parts. Islam et al. [3] found that several factors influence the quality of drilled holes such as cutting parameters and cutting tool configurations. Prajapati et al [4] optimized the parameters for surface roughness (SR) and material removal rate (MRR) in CNC turning. SS 316 (austenite steel) work material of Ø 45 mm and length 35 mm was used in turning in dry environment conditions. In this study, the effect and optimization of machining parameters (rotational speed, vertical feed rate and drill diameter) on SR and MRR is investigated. A L27 Orthogonal array, analysis of variance (ANOVA) and grey relation analysis is used. Chandrasekaran et al. [5] studied the machinability of AISI 410 on CNC lathe for SR using Taguchi method. The effect and optimization of machining parameters on SR was investigated. L27 Orthogonal array, analysis of variance (ANOVA) was used in this investigation. The experiment was conducted on FANUC CNC lathe. Work material of Ø 32 mm and length 60 mm was used. Kivak et al. [6] employed Taguchi method to optimize drilling parameters for surface roughness and thrust force in dry cutting conditions of AISI 316. Cicek et al. [7] studied the effects of cryogenic treatment and drilling parameters of AISI 304 stainless steel under dry conditions. They investigated that rotational speed and vertical feed rates are most significant factors with percentage contribution of 83.07% and 64.365% respectively on surface roughness and roundness error. Ilhan et al. [8] performed dry turning on hardened AISI 4140 and optimized turning parameters to minimize surface roughness. Tsao et al [9] investigated a prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The objective of their study was to establish a correlation between spindle speed, vertical feed rate and drill diameter. Rao et al. [10] presented a comprehensive study of delamination in use of various drill types, three different feed rate and spindle speeds. Kilickap [11] investigated the influence of the machining parameters, such as cutting speed and vertical feed rate, and point angle on delamination produced when drilling a glass-fibre reinforced plastic (GFRP) composite.

The survey of literature indicates that there are published works on the effect of process parameters on surface roughness. However, very limited literature is available on the study of the effect of drilling process parameters on high carbon high chromium (HCHCr) steel bars. Due to wide range of applications of HCHCr an attempt has been made in this study to optimize deep drilling parameters such as rotational speed, vertical feed rate and drill diameter for minimum value of surface roughness. In this study the experiments are conducted on CNC vertical milling machine for machining parameters like spindle speed, vertical feed rate and drill diameter to analyze the process parameters depth of the pocket. Taguchi method is used to obtain the optimal combination of the milling process parameter and ANOVA is used to investigate which milling parameter significantly affected the performance characteristic.

2. EXPERIMENTAL WORK

2.1 MATERIALS AND MACHINE USED

2.1.1 MATERIAL OF WORK PIECE

Cold-work tool steels include the high-carbon, high-chromium steels or group D steels. These steels are designated as group D steels and consist of D2, D3, D4, D5, and D7 steels. These steels contain 1.5 to 2.35% of carbon and 12% of chromium. Except type D3 steel, all the other group D steels include 1% Mo and are air hardened. Type D3 steel is oil-quenched; though small sections can be gas quenched after austenitization using vacuum. As a result, tools made with type D3 steel tends to be brittle during hardening. Type D2 steel is the most commonly used steel among the group D steels and is used in present study as work-piece material of 120 x 100 x 25 mm size. The composition of the work-piece material is shown in Table.1 and Table 2.

Table 1: Chemical Composition of HCHCr tool steel

Element	Content (%)
C	1.40 – 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 – 13.00
Mo	0.70 – 1.20
V	1.10
P	0.03
Ni	0.30
Cu	0.25
S	0.03

Table 2: Chemical Composition

C	Si	Cr	Mo	V
1.50%	0.30%	12.00%	0.80%	0.90%

2.1.2 Machine

The drilling operations are carried out on a Vertical CNC milling machine with three carbide drills having diameters of 8mm, 10mm, 12mm as shown in Fig 1. The surface roughness values were measured by the surface roughness tester (model: SURFTEST, SV-2100; make: **Mitutoyo, Japan.**

2.2 Experimental Procedure

The experimental studies were performed on a vertical milling machine. This machine can be used to cut work-piece in accordance with the predetermined locus (experimental setup is shown in Fig.1). The experiments were conducted with three controllable 3-level factors and one response variables. Nine experimental runs based on the orthogonal array L9 were performed. The holes were cut using drill of different diameters as shown in Fig 2. Small values of surface roughness were considered. The surface roughness of the work piece was measured using surface roughness testing machine. The average surface roughness (*Ra*) was chosen as a measure of surface quality.

Fig 1. Experimental setup

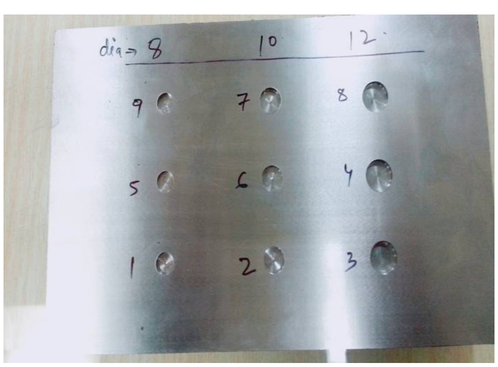

Fig 2. Drilled work piece

2.2.1 Experimental Parameters and Design

Taguchi method, a powerful tool for parameter design of performance characteristics, was used to determine optimal machining parameters for minimum surface roughness in drilling. In Taguchi method, process parameters which influence the products are separated into two main groups: control factors and noise factor. The control factors are used to select the best conditions for stability in design of manufacturing process, whereas the noise factors denote all factors that cause variation. Taguchi proposed to acquire the characteristic data by using orthogonal arrays, and to analyze the performance measure from the data to decide the optimal process parameters. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only, According to the Taguchi quality design concept, there are three categories of performance characteristics in the analysis of the S/N ratio:

2.2.2 Taguchi Method

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The Taguchi technique is a methodology for finding the optimum setting of the control factors to make the product or process insensitive to the noise factors. Taguchi's such as optimization, experimental design, sensitivity analysis, parameter estimation, model prediction, etc. Robust design process consists of three steps, namely system Design, parameter Design and Tolerance Design. Taguchi based optimization technique has produced a unique and powerful optimization discipline that differs from traditional practices. While, traditional experimental design methods are sometimes too complex and time consuming. Taguchi method uses a special highly fractionated factorial designs and other types of fractional designs obtained from orthogonal arrays (OA) to study the entire experimental region of interest for experimenter with a small number of experiments. This reduces the time and costs of experiments, and additionally allows for an optimization of the process to be performed. The columns of an OA represent the experimental parameters to be optimized and the rows represent the individual trials (combinations of levels). Traditionally, data from experiments is used to analyze the mean response. However, in Taguchi method the mean and the variance of the response (experimental result) at each setting of parameters in OA are combined into a single performance measure known as the signal-to-noise (*S/N*) ratio. Depending on the criterion for the quality characteristic to be optimized, different *S/N* ratios can be chosen:

Smaller – The –Better The Signal-To-Noise ratio for the Smaller-The-Better is: S/N = -10 *log (mean square of the response)

$$\eta = 10\ln 10\frac{1}{n}\sum_{i=1}^{n} y i2$$

Larger – The – Better The Signal-To-Noise ratio for the bigger-the-better is: S/N = -10*log (mean square of the inverse of the response)

$$\eta = 10\ln 10\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$$

Where n= number of measurements in trial/row, in this case n=1, 2…, 9 and Yi is the ith measured value in a run/row. i =1, 2………

Nominal – The – Better The S/N equation for the Nominal-The-Best is: S/N = 10 * log (the square of the mean divided by the variance)

$$\eta = 10\ln 10\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2}$$

The Taguchi method provides an effective experimental design with reduced number of experiments for conducting experiments and subsequent data analysis. Due to the advantages offered by this method, researchers have used this method in the drilling operations. In the present study, the Taguchi design of experiments was used to investigate the effect of the machining parameters on surface roughness (Ra) of the holes generated by drilling bits on vertical drilling machine. The lower-the-better criterion for Ra was chosen to calculate the S/N ratio, since low value of surface roughness is required for obtaining better performance.. The S/N ratio was calculated by using equation-

$$S/N = -10\log\left[1/n\sum_{i=1}^{n} yi2\right]$$

2.2.3 Design of Experiments (DOE) and Process Parameters

The DOE helps us for conducting experiments in a more systematic way. The process parameters levels are specified in Table 3 below.

Table 3. Experimental factors and their levels

Factor	Symbol	Level-1	Level-2	Level-3
Spindle speed	A	1000	2000	3000
Vertical Feed rate	B	5	10	15
Drill Diameter	C	8	10	12

2.3.4 Orthogonal Array

Orthogonal array is a statistical method of defining parameters that converts test areas into factors and levels. It allows for the maximum number of main effects to be estimated in an orthogonal manner, with minimum number of runs in experiment in this study an L9 orthogonal array was used.

Table 4: Orthogonal array L9 of the experimental runs

S. No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

3. Results and Discussions

The following sections describe the results of the present study and also present a discussion on the results in light of the available literature. Effect of drilling machining parameter on surface roughness of high carbon high chromium (HCHCr) steel was successfully investigated. Measured values of surface roughness and corresponding signal-to-noise (S/N) ratio as per the Taguchi's L9 orthogonal array is shown in Table5. Table 6 shows the mean S/N ratio at each level of the machining parameters. The different values of the S/N ratio between maximum and minimum (main effect) are also shown in Table 6. The analysis of variance (ANOVA) was conducted to study the significance of machining parameters on surface roughness based on their F-value at 5% level of significance.

Table 5. Orthogonal array L9 of experiments and results

S. No.	A	B	C	Ra	SN ratio
1	1	1	1	2.619	-8.3627
2	1	2	2	2.918	-9.3017
3	1	3	3	3.241	-10.2136
4	2	1	3	1.691	-4.5629
5	2	2	1	2.915	-9.2928
6	2	3	2	3.813	-11.6253
7	3	1	2	1.278	-2.1306
8	3	2	3	1.727	-4.7458
9	3	3	1	1.932	-5.7201

3.1 Analysis of Mean (ANOM)

The spindle speed and feed are two factors with the highest different in values of 5.094 and 4.168 respectively. Greater the difference in value of S/N ratio shows greater effect or more significant. Therefore, increase changes in the spindle speed reduce the roughness significantly.

Table 6. Response Table for Signal to Noise Ratios

S NO.	Symbol	Level 1	Level 2	Level 3
1	A	-9.293	-8.494	-4.199
2	B	-5.019	-7.780	-9.186
3	C	-7.792	-7.686	-6.507

3.2 Analysis of variance (ANOVA)

The ANOVA results are shown in Table 7. It can be seen that the spindle speed and vertical feed rate significantly affects the surface roughness as F calculated value is more than the tabulated F value (F0.05, (2,2) = 19) whereas, drilling diameter does not have significant effect on surface roughness. However, based on the percentage contribution of the machining parameters shown in Table 7, it is found that percentage contribution of spindle speed (56.61.%) is maximum followed by vertical feed rate (33.91%) and drilling diameter (3.834%).

. **Table 7. Analysis of Variance for SN ratios**

Sources of variation	Sum of square	DOF	Mean square	F value	Contribution %
Spindle speed(A	45.030	2	22.515	10.05	56.618
Vertical feed rate (B)	26.972	2	13.486	6.02	33.913
Drilling Diameter (C)	3.050	2	1.525	0.68	3.834
Error	4.480	2	2.240		5.632
Total	79.532	8			100

3.3 Plots

Fig.3 shows the normal probability plot of the residuals for the surface roughness and it reveals that the residuals either fall on a straight line or are very close to the line implying that the errors are distributed normally.

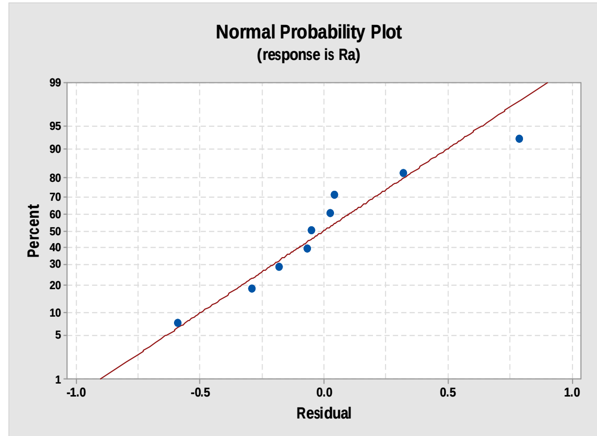

Fig 3 Normal probability plot

Fig.4 depicts the main effect plot for S/N ratio. It can be seen that the surface roughness decreases with the decrease in feed rate, increase in spindle speed and increase in drilling diameter. However, it is seen that the effect of depth of cut is very small on the surface roughness. Based on the results shown in Table 6 and Fig.4, it can be seen that the optimal combination of the machining parameters for surface roughness **$A_3B_1C_3$**, i.e., at spindle speed (A) at **3000** rpm, vertical feed rate (B) at **5** mm/min, and drilling diameter (C) at **12** mm.

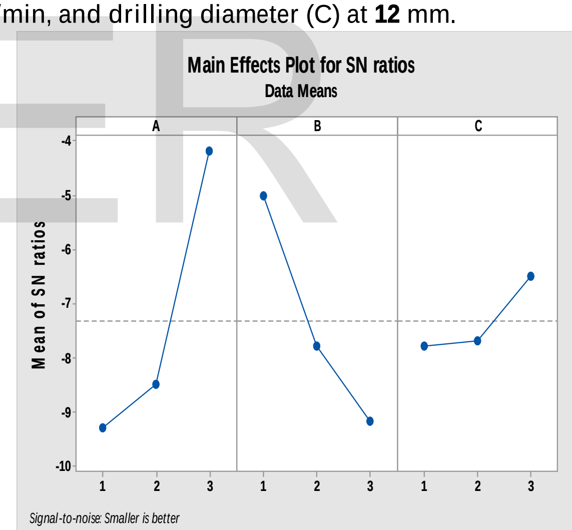

Fig. 4 Main effect plot for SN ratios

Optimized parameter combination (**$A_3B_1C_3$**,) obtained from Taguchi method is not available in the L9 orthogonal array used in the present study. Therefore confirmation test was conducted at the optimized parameter combination and minimum surface roughness of 1.265 µm was obtained.

4. Conclusions

In this study, investigation on the effect of drilling process parameters (spindle speed, vertical feed rate and drill diameter) on the surface roughness during drilling of high carbon high chromium (HCHCr) is carried out. The drilling parameters are optimized using Taguchi method for obtaining minimum surface roughness of drilled hole. Results revealed that $\mathbf{A_3B_1C_3}$ is found to be optimized parameter combination for getting minimum surface roughness. Minimum roughness was found at spindle speed of 3000 rpm, vertical feed rate of 5 mm/min and drill diameter of 12mm. Based on the percentage contribution of the machining parameters it is found that percentage contribution of spindle speed (56.61.%) is maximum followed by vertical feed rate (33.91%) and drilling diameter (3.834%). Confirmation test was conducted at the optimized parameter combination and minimum surface roughness of 1.265 µm was obtained.

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