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# Analysing the Deep Hole Drilling Characteristics of AISI 316 Alloy Using Peck Drilling Approach

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***Abstract***

*This study aims at the deep hole drilling characteristics of AISI 316 alloy utilizing the Peck drilling procedure. It is well-established that hole is the most prevalent machining process, requiring precise techniques to achieve optimal cutting conditions. AISI 316 has high corrosion resistance and mechanical features. It is widely utilized in the aerospace, vehicle, aircraft, and other industries. Due to its high modulus of elasticity, reactivity at high cutting speeds, low heat conductivity, high ductility, high tensile strength, high toughness, high work-hardening rates, and the formation of built-up edge (BUE), machining stainless steel is recognized as extremely challenging. Scientific methods for selecting cutting environments for damage-free drilling operations need to be achieved in order to minimize machining challenges. The experiments are designed using a Taguchi L9 array, with three factors considered at three levels each. The present study is focused on the notion of intermittent drilling and retraction, which is applied using a CNC vertical milling machine, and the outcomes are analyzed. The collected statistics reveal that hole numbers 6 and 7 have reduced roundness. The M35 tool at 800 rpm and a feed rate of 0.05mm/rev yielded the lowest roundness value, followed by the TiAlN tool at 700 rpm and a feed rate of 0.15mm/rev. Cylindricity is within 0.02 for holes 6, 5, and 4 machined with an M35 drill bit, and within 0.04 for holes machined with HSS drill bits. The process parameters are tuned to get the best drill condition.*

**Keywords:** Deep hole drilling, circularity, cylindricity, AISI 316, Taguchi approach.

## INTRODUCTION

Deep hole drilling is a specialized machining process used for creating holes with considerable depth-to-diameter ratios. Drilling is a vital procedure in the manufacturing sectors which involves making holes. It is extensively used in the aerospace sector, automobile, airplane, and many more industries. D.Biermann et al. mentioned a deep hole is characterized by its depth-to-diameter ratio (D:d), and holes with larger than 10:1 ratio are usually called deep holes [1]. Ramachandran et al. reported that, ANOVA and linear regression analysis are used to determine the significant control factors affecting the surface roughness in drilling stainless steel [2]. To improve the machining processes in deep hole drilling it is found that the chip evacuation behaviour of the drilling tool plays a significant role. The work also discussed on various approaches will aid researchers and industry professionals in discovering innovative machining techniques. [3]. Circularity, cylindricity and perpendicularity are a few of most sought-after geometrical properties of machined components in the industry and quite a good extent of research is demonstrated towards obtaining the desired limits of such geometrical parameters through machining processes [4,5]. Arshad Noor Siddiquee et al. optimized deep drilling parameters using the Taguchi method to minimize surface roughness. The experiments were

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carried out on a CNC lathe utilizing a solid carbide cutting tool and AISI 321 austenitic stainless steel [6]. Khushboo Sharma et al performed an experimental investigation to optimize the machining parameters of AA6082. Control elements such as feed rate, speed, presence or absence of cutting fluid and hole depth are consideration to maximize the MRR and surface roughness [7].

Sundar Singh Sivam et al, aim to identify optimal drilling conditions for AM60 magnesium alloy. The results of drilling AM60 magnesium alloy are optimized using the ANOVA technique. The result of speed, feed, drilling time and drill bit treatment was investigated and various outcomes were discussed [8]. Tarakeswar Barik et al, from the experiment on drilling CFRPs found that machine parameter settings and angle of drill point have a significant influence on hole quality [9]. The work reported that, optimized set of input parameters were identified by Alagappan KM et al, for drilling hybrid FRP using WC coated HSS drills was studied [10]. C Sarala Rubi et al aims to investigate how process variables including reinforcement, drill type, speed, and feed rate affect the thrust force and burr height during AMCs drilling [11]. Esmaeil Damavandi et al, performed optimisation of the deep drilling process using the Taguchi method on three materials with three distinct cutting tools in order to investigate their effect on power tool wear and surface roughness [12]. The reported work deals the drilling parameters are optimized, the Taguchi method is employed to minimize thrust force and surface roughness (Ra). (Ff), and ANOVA was used to identify the significant parameter influencing surface roughness and thrust force [13].

The influence of cutting parameters such as cutting speed, feed rate, and helix angle on tool life. The studies were conducted on AISI304 steel with carbide drill bits. Cutting parameters' effects were investigated by measuring the amplitude of drill bit vibration and surface roughness [14]. A 6° increase in drill tip angle resulted in a more than 150 N decrease in feed force. In addition, increasing the clearance angle by 1° resulted in a 70 N drop in feed force. The experiment's results revealed that with the proper tool geometry, successful machining without the use of internal cooling is possible [15]. Deep hole drilling typically serves the following domains in its respective applications: Aerospace and defence, automotive applications, oil and gas exploration. To improve product quality, cutting settings and factors should be carefully determined.

The peck drilling method used for deep hole drills was not thoroughly explained in previous studies, and the current research is primarily concerned with studying the effects of process parametrs on deep hole drilling and determining the ideal drill parameters for deep hole drilling AISI 316. This study investigates the effects of cutting settings and tools (HSS, M35, TiAlN) on the surface quality, shape, and geometrical tolerances of deep hole drilled holes in AISI 316. Choosing the appropriate drill bits is critical to successful stainless-steel drilling.

## MATERIAL AND METHODS

### Workpiece

Deep hole drilling experiments are conducted on SS 316 material of diameter 100 mm and thickness 50mm. Stainless steel is harder to machine and requires special tools for cutting. Stainless steel 316 is generally composed of 16–18% chromium, 10–14% nickel, 2–3% molybdenum, and about 0.08% carbon.

### Cutting Tools

The quality of work can be improved by altering machining conditions such as coolant type, cutting tool type, cutting tool radius, tool material type, and working material hardness. The coating helps reduce heat buildup, improves chip evacuation, and extends tool life. Drill bits with coatings have higher tool life than the drills uncoated [16]. Nevertheless, drill bit flute geometry is the most significant factor influencing hole quality and chip evacuation from drilling zone [17-18]. In the present work three different tools are considered for drilling namely, High-Speed Steel (HSS) Drills, M35 HSS Cobalt Drills and TiAlN-Coated Drills. The nominal diameter of each tool is 5 mm and the flute length is 52 mm. The details of drill bits are shown in Table 1.

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**Table 1.** Specifications of drill bits.

| S no | Drill material | Tool nominal diameter (mm) | Flute length (mm) | Tool profiles |
|---|---|---|---|---|
| 1 | HSS | 5 | 52 |  |
| 2 | M35 | 5 | 52 |  |
| 3 | TiAlN | 5 | 52 |  |

**CNC Milling Machine**

Deep hole drilling on stainless steel is done on a vertical CNC milling machine using the peck drilling method. Peck drilling is a technique for optimizing chip removal and coolant delivery during deep hole drilling operations. Retracting the drill bit on a regular basis breaks up and evacuates chips from the hole, lowering the risk of chip blockage and heat accumulation.

The machining time in CNC milling is the cycle time required by the CNC machine to execute the program for each hole, and it is much longer than the theoretical time when computed due to tool retraction each time it reaches the through hole for the specified depth of cut. The real machining time will be more than the theoretical time. The variation between real and theoretical machining time is attributable to the tool and work material, as well as the time necessary for retraction for each depth of cut when drilling a 50mm through hole. For each depth of cut, the tool retracts to its original position, allowing for simple chip evacuation with coolant. Thus, nine through holes with a diameter of 5mm are created. Figure 1 illustrates the operating concept of the drilling operation. The procedure parameters employed in these trials are listed in Table 2.


**Figure 1.** CNC milling machine and workpiece.

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**Table 2.** Factors and Levels

| Factors | Level | | |
|---|---|---|---|
| | *1* | *2* | *3* |
| Drill Material | HSS | M35 | TiAlN |
| Spindle Speed (rev/min) | 700 | 750 | 800 |
| Feed Rate (mm/rev) | 0.05 | 0.1 | 0.15 |

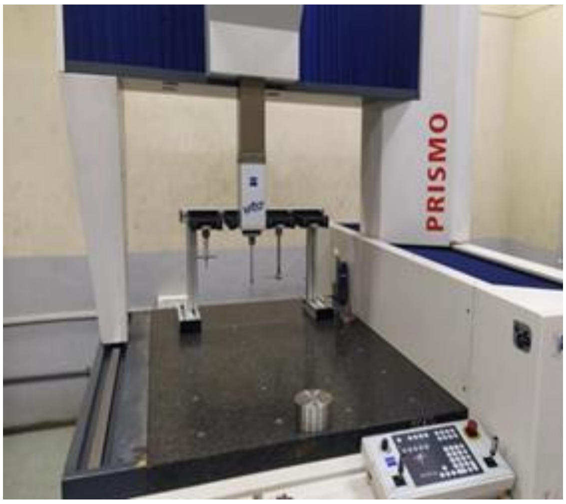


**Figure 2.** Coordinate measuring machine.

**Coordinate Measuring Machine (CMM)**

The measuring of hole dimensions is critical in guaranteeing that the manufactured part's tolerance values are within the limit and lowering mistake rates. It is manufactured by ZEISS PRISMO and operated using CALYPSO software. Cylindricity tolerance refers to a 3D tolerance on hole size along its length that is regulated by two concentric cylinders [19-20]. Cylindricity is a type of composite form tolerance that governs circularity, surface straightness, and cylindrical feature taper all at once [21]. To calculate cylindricity, three measurements are required: radial form (roundness), axial form (vertical straightness), and dimensional homogeneity, different methods are used [22].

Perpendicularity can refer to two distinct phenomena: surface perpendicularity and axis perpendicularity. To guarantee that the probe head is normal to the workpiece, several spots on the top surface were mapped. The hole axis shifts away from the reference plane (top plane), indicating a hole perpendicularity issue [23]. Figure 2 illustrates the CMM machine configuration.

**RESULTS AND DISCUSSIONS**

**Measurement of Hole Surface Roughness**

Surface roughness is an important property in metal cutting; it is controlled by drilling operations and impacts mechanical qualities such as creep life, corrosion resistance, and fatigue behaviour. Drilled surface roughness is measured using the IS 3073:1967 surface testing procedure. The average surface roughness (Ra) is determined by measuring a minimum of five locations along the direction of hole depth, and the average is used to get the final result. Surface roughness is commonly measured with a stylus movement device, which measures the depth-wise variations of the surface profile, with larger variations indicating rough surfaces. Surface polish is critical for drilled hole quality, and even little roughness can impair operations and product reliability.

Table 3 shows the machining time achieved from a CNC machine for drilling each hole for the stated parameters. According to the CNC code, drilling a 50mm through hole requires 250 pecks with a depth of 0.2mm. Given an average retraction length of 25 mm during the process. The feed rate at 700 rpm

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and 0.1mm/rev is 70mm/min, or 1.1mm/s. The peck time for 250 pecks at a depth of 0.2mm is 50 seconds. For 250 pecks with a 25 mm retraction length, the total forward and retraction time is (2x25/8.3) x 250 seconds, assuming a feed speed of 500mm/min = 8.3mm/s. That is, machining time equals peck time plus retraction time for 250 pecks. = 50 + 1506 = 1556 seconds = 25.9 minutes. The tool retracts at 850rpm for each peck depth, which is quicker than the actual drilling speed, saving machining time. Drilling hole No.3 takes less time to machine, at 8 minutes and 39 seconds with an HSS tool. The values for roundness, cylindricity, dimension, and perpendicularity are provided in Table 3.

The data collected demonstrate that hole numbers 6 and 7 have reduced roundness. The lowest roundness value was achieved with the M35 tool at 800 rpm and a feed rate of 0.05mm/rev, followed by the TiAlN tool at 700 rpm and a feed rate of 0.15mm/rev.

Cylindricity is at its lowest for holes 6, 5, and 4, which were machined using an M35 drill bit. Specifically, hole 4, drilled with the M35 bit at a speed of 700 rpm and a feed rate of 0.1 mm/rev, achieved a minimum diameter of 5.5593 mm. During these trials, both M35 and HSS tools exhibited considerable wear when compared to TiAlN drills, which yielded hole diameters ranging from 5.76 mm to 5.87 mm. The variations in hole diameters cannot be solely ascribed to roundness or cylindricity inaccuracies, suggesting that elastic recovery of the workpiece may also play a role, in addition to potential tool wear. Among the holes, hole 2 displayed the smallest perpendicularity angle. The differences in perpendicularity were not significant across various drill materials, speeds, and feed rates. The machining times recorded are detailed in Table 3.

The collected data indicate that the roundness is notably lower for hole numbers 6 and 7. The minimum roundness value was recorded when utilizing the M35 tool at 800 rpm with a feed rate of 0.05 mm/rev, as well as with the TiAlN tool at 700 rpm and a feed rate of 0.15 mm/rev. For holes 6, 5, and 4, machined with the M35 drill bit, the cylindricity remains at a minimum of 0.02, while it is measured at 0.04 for those drilled with HSS tools. The performance of TiAlN drills in terms of cylindricity has been subpar, exhibiting values ranging from 0.066 to 0.131. The smallest hole diameter of 5.56 mm was achieved for hole 4, drilled with the M35 tool at 700 rpm and a feed rate of 0.1 mm/rev, which may be attributed to potential drill wear.

In the conducted experiments, M35 and HSS tools exhibited significantly greater wear when compared to TiAlN drills, which achieved hole diameters ranging from 5.76 to 5.87 mm. As illustrated in Figure 10 (a-c), the variations in hole diameter cannot be solely ascribed to errors in roundness or cylindricity, suggesting the potential influence of elastic recovery in the workpiece in addition to tool wear. Notably, Hole 2 displayed the smallest perpendicularity angle. The differences in perpendicularity are not substantial across various drill tool materials at differing speeds and feeds. The recorded surface roughness values are presented in Table 4.

**Table 3.** Machining Time for drilling holes.

| Hole no. | Tool | Speed (rpm) | Feed (mm/rev) | Depth of cut (mm) | Machining time (minutes) | Roundness | Cylindricity | Diameter | Perpen-dicularity |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HSS | 700 | 0.05 | 0.2 | 17.4 | 0.0142 | 0.0362 | 5.5931 | 0.3628 |
| 2 | HSS | 750 | 0.1 | 0.2 | 9. 41 | 0.0058 | 0.0226 | 5.6040 | 0.3341 |
| 3 | HSS | 800 | 0.15 | 0.2 | 8. 39 | 0.0138 | 0.0239 | 5.6018 | 0.4164 |
| 4 | M35 | 700 | 0.1 | 0.2 | 10. 29 | 0.0146 | 0.0194 | 5.5593 | 0.3865 |
| 5 | M35 | 750 | 0.15 | 0.2 | 8. 45 | 0.0122 | 0.0193 | 5.5605 | 0.3874 |
| 6 | M35 | 800 | 0.05 | 0.2 | 13. 46 | 0.0099 | 0.0192 | 5.5649 | 0.3822 |
| 7 | TiAlN | 700 | 0.15 | 0.2 | 9. 18 | 0.0029 | 0.0956 | 5.8735 | 0.3769 |
| 8 | TiAlN | 750 | 0.05 | 0.2 | 25. 45 | 0.0149 | 0.0664 | 5.8340 | 0.4217 |
| 9 | TiAlN | 800 | 0.1 | 0.2 | 9. 36 | 0.0261 | 0.1310 | 5.7580 | 0.3947 |
| Avg | | | | | | 0.0127 | 0.0481 | 5.6610 | 03847 |

**Table 4.** Surface Roughness values for drilled holes.

| Hole no. | Test parameter | Test method | Result | | |
|---|---|---|---|---|---|
| | | | *Ra (μm)* | *Rq (μm)* | *Rz (μm)* |
| 1 | Surface Roughness | IS 3073:1967 | 1.004 | 1.239 | 4.977 |
| 2 | | | 1.366 | 1.663 | 7.290 |
| 3 | | | 1.029 | 1.241 | 4.768 |
| 4 | | | 1.721 | 2.155 | 8.813 |
| 5 | | | 1.164 | 1.534 | 7.096 |
| 6 | | | 1.528 | 1.929 | 7.802 |
| 7 | | | 1.461 | 1.815 | 7.324 |
| 8 | | | 1.095 | 1.317 | 5.341 |
| 9 | | | 1.984 | 2.548 | 10.880 |
| Avg | | | 1.372 | 1.715 | 7.143 |

Table 5 illustrates the effects of spindle speed and feed rate on hole surface roughness Ra. It is noted that the roughness values Ra vary between 1.004 μm and 1.984 μm. The feed rate appears to have a minimal impact on roughness, whereas a decrease in spindle speed is recommended for achieving smoother surfaces.

These results indicate that selecting low to medium spindle speeds and feed rates can effectively yield a refined hole finish. Tool speed plays a crucial role in influencing hole surface roughness. The measurements of Surface Roughness Ra and Rq are lower for hole number 1, while Rz is reduced for hole number 3.

## TAGUCHI ANALYSIS

Optimization techniques are used to reduce manufacturing cost, improve surface quality, reduce circularity, cylindricity and diameter error in machining [24,25]. S Sheth et al. concentrated on cylindricity and perpendicularity as output parameters in the drilling process since cylindricity and perpendicularity control are critical in the assembly of two matting components with holes [26].

The smaller-the-better type of drilling performance criteria may be applied for response parameters including surface roughness, hole diameter deviation and geometrical tolerance parameters [27]. The Taguchi method is a sophisticated experimental design method that uses orthogonal arrays to study total parameters and responses with limited experiments. A special design of "orthogonal arrays" is utilized to explore the whole parameter range with a limited number of trials. Table 1 shows the factors controlling the drilling process and their levels in this experiment while Taguchi L9 Orthogonal Array of experimental design is shown in Table 4. It shows the combination of control factors and their levels for conducting the nine experimental runs. Surface roughness, hole diameter, cylindricity, roundness, and perpendicularity are the responses that make up the experimental outcomes. This allows for the best possible parameter assessment. According to Taguchi's procedures, the mean of the S/N ratios is determined by adding them together for each level and parameter. To obtain the response table for every response element under various control factors and their levels, Minitab software is utilized. S/N ratios in optimization problems come in three different varieties. These are: Nominal is the best, larger is the best, and smaller is better. In order to minimize the response variables—roundness, roughness, cylindricity, perpendicularity, and diameter variation—the quality characteristic "Smaller the better" was selected in this instance [28–29].

### Analysis of Variance (ANOVA)

The mathematical formula to forecast the experiment's results was established by R.A. Fisher [33] using the analysis of variance (ANOVA). The ANOVA test was used to evaluate each parameter's contribution at a confidence level of 95%, and the P value is used to identify the significant parameter if its value is less than 5% (0.05).

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**Regression Equation**

A regression equation is a mathematical formula that is used to represent the relationship between one or more independent variables (predictors or inputs) and one or more dependent variables (output). Regression analysis uses the values of the independent variables to predict the value of the dependent variable.

**Roundness**

The degree to which the shape of a drilled hole resembles a perfect circle is known as roundness. In precision machining, where the roundness of the hole affects component fit and performance, it is a crucial geometric feature. A coordinate measurement machine (CMM) or a roundness tester are examples of specialist equipment that is commonly used to measure roundness [30]. By measuring multiple radial locations around the hole's perimeter, these devices determine how much the drilled hole deviates from a perfect circle. Process variables that primarily affect the drilled hole's roundness include tool material, speed and feed rates, machine rigidity, material qualities, and chip removal [31]. The roundness in drill holes is crucial for the functionality of parts, and maintaining precision requires careful attention to tool condition, machine setup, and operational parameters.

Roundness is the primary response aspect for defining the quality of drilled holes. To evaluate the effect of process parameters on roundness, computed means and S/N ratios for each factor are generated. To maximize roundness, the S/N ratio was set using the criterion "smaller is better." The Taguchi technique calculates the deviation of quality attributes from the desired value using the S/N ratio. The means of the response values for the parameter levels shown in Figure 3 are determined using the S/N ratio.

The ANOVA test results showed that no parameter has a significant value, and all values are greater than 5%. The roundness value ranges between 0.0058 and 0.0261. The smallest roundness value is 0.0058, while the maximum roundness value is 0.0261. The estimated F and P values for the drill parameters are shown in Table 5.

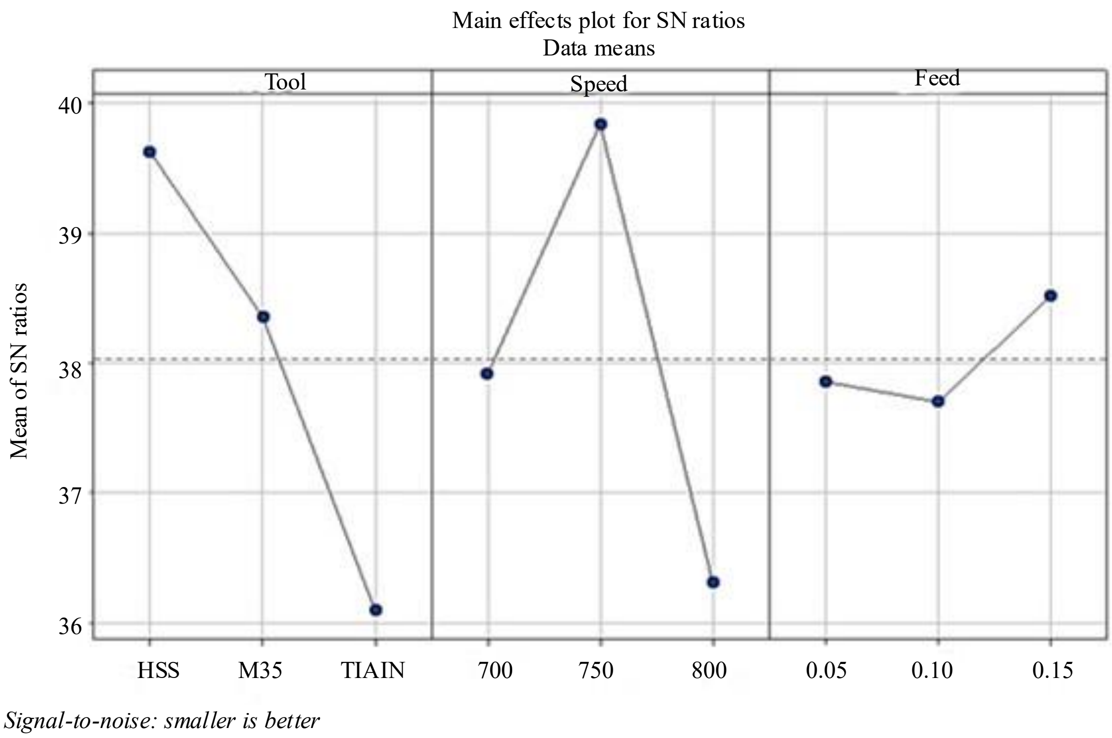


**Figure 3.** S/N ratio of roundness

**Table 5.** ANOVA results of Roundness

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | |
|---|---|---|---|---|---|---|
| Drill Material | 2 | 0.010734 | 0.005367 | 10.92 | 0.084 | Significant |
| Spindle Speed | 2 | 0.000524 | 0.000262 | 0.53 | 0.652 | |
| Feed Rate | 2 | 0.000665 | 0.000333 | 0.68 | 0.596 | |
| Error | 2 | 0.000983 | 0.000492 | | | |
| Total | 8 | 0.012907 | | | | |

**Regression Equation**

The regression equation consists the arrangement of all the process parameter according to their level and corresponding coefficient term expressed in equation 1.

$$\text{Roundness} = 0.01349 - 0.00222\,(T1) - 0.00126\,(T2) + 0.00348(T3) - 0.00059\,(S1) - 0.00252\,(S2) + 0.00311\,(S3) - 0.00049\,(F1) + 0.00201\,(F2) - 0.00152\,(F3) \quad (1)$$

**Cylindricity**

The geometric correctness of the hole's shape as a perfect cylinder is referred to as cylindricity. It gauges how closely the hole resembles the ideal cylindrical shape, which calls for a circular hole with a straight, aligned axis and a constant diameter throughout. Parts that must match or mate with other components must have a cylinder to ensure proper fit and operation [32]. Cylindricity can be assessed using specialist instruments as a dial gauge, coordinate measuring machine (CMM), or cylinder tester. Cylindricity is primarily determined by the diameter's consistency, the hole axis's straightness, and its circularity.

Cylindricity is the primary response aspect that defines the quality of drilled holes. To analyze the effect of process parameters on cylindricity, computed means and S/N ratios for each factor are generated. To maximize cylindricity, the S/N ratio was set using the criterion "smaller is better." To assess the deviation of quality attributes from their ideal levels, the Taguchi technique employs the S/N ratio. The average response values at the parameter, as illustrated in Figure 4, are using the S/N ratio.

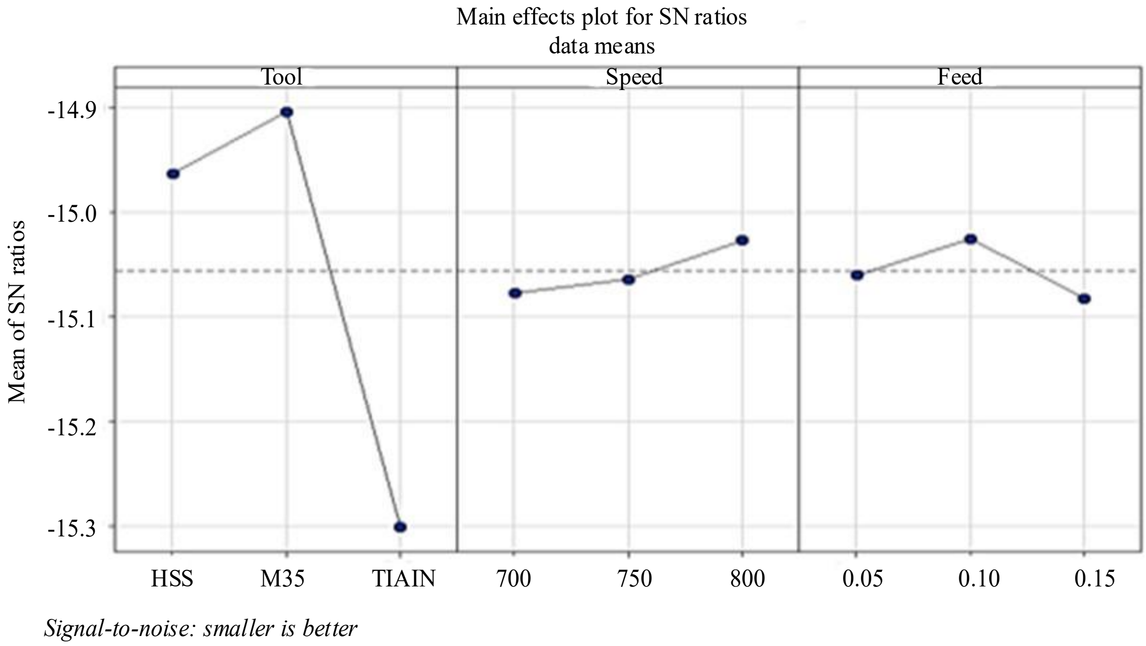


**Figure 4.** Main effects plot for S/N ratio of cylindricity.

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The ANOVA test findings showed that the parameter drill material had a significant value, with a P-Value of 0.084, which is less than 5%. The cylindricity values range from 0.0192 to 0.0956. The minimum roundness value is 0.0192; the maximum roundness value is 0.0956. The estimated F and P values for the drill parameters are shown in Table 6.

**Table 6.** ANOVA Results of Cylindricity.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | |
|---|---|---|---|---|---|---|
| Drill Material | 2 | 0.010734 | 0.005367 | 10.92 | 0.084 | Significant |
| Spindle Speed | 2 | 0.000524 | 0.000262 | 0.53 | 0.652 | |
| Feed Rate | **2** | 0.000665 | 0.000333 | 0.68 | 0.596 | |
| Error | 2 | 0.000983 | 0.000492 | | | |
| Total | 8 | 0.012907 | | | | |

**Regression Equation**

The regression equation consists the arrangement of all the process parameter according to their level and corresponding coefficient term expressed in equation 2.

Cylindricity = 0.04929- 0.0184(T1)- 0.0300(T2) + 0.0484(T3) + 0.0011 (S1)- 0.0099 (S2) + 0.0087 (S3)- 0.0087 (F1) + 0.0117 (F2) - 0.0030 (F3) (2)

**Hole Diameter**

The internal diameter of the hole made by a drilling operation is referred to as the "hole diameter" in drilling. Because it affects the fit and functionality of later-assembled or machined parts, the hole's size is crucial in many manufacturing processes. Ensuring that the hole performs as intended in its application, enabling bolts, pins, and shafts to fit correctly, and facilitating proper assembly all depend on achieving the proper hole diameter [33–36]. The hole diameter in the drilling process is mostly influenced by the following factors: drill bit size and type; drilling conditions; material properties; tool wear; machine rigidity and alignment; heat generation; and drilling technique.

Hole diameter is the primary response element in determining the quality of drilled holes. To evaluate the effect of process parameters on hole diameter, computed means and S/N ratios for each factor are generated. In this study, the S/N ratio was determined using the "smaller is better" criterion to optimize hole diameter. In the Taguchi technique, the S/N ratio is used to determine the divergence of quality characteristics from the target value. The S/N ratio is utilized to determine the means of the response values at the parameter level depicted in Figure 5.

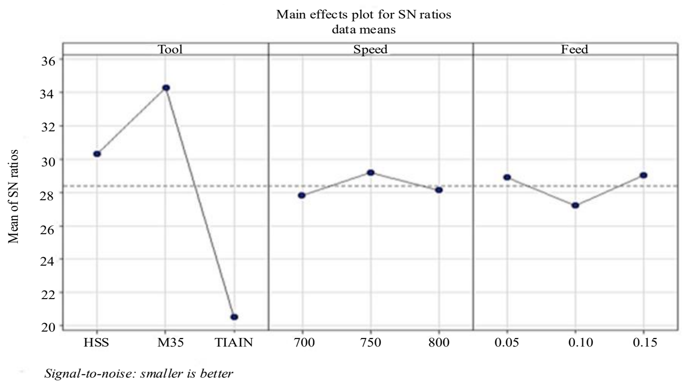


**Figure 5.** Main effects plot for S/N ratio of diameter.

**Table 7.** ANOVA Results of Hole diameter.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | |
|---|---|---|---|---|---|---|
| Drill Material | 2 | 0.118561 | 0.059280 | 40.54 | 0.024 | Significant |
| Spindle Speed | 2 | 0.001827 | 0.000913 | 0.62 | 0.616 | |
| Feed Rate | 2 | 0.002225 | 0.001113 | 0.76 | 0.568 | |
| Error | 2 | 0.002924 | 0.001462 | | | |
| Total | 8 | 0.125537 | | | | |

The ANOVA test findings revealed that the parameter drill material has a significant value, with a P-value of 0.024, which is less than 5%. The hole diameter varies from 5.5605 to 5.8735. The minimum hole diameter is 5.5605, while the maximum roundness value is 5.8735. Table 7 shows the estimated F and P values for the drill parameters. The measured data clearly demonstrated that all of the hole diameters have extremely similar values.

**Regression Equation**

The regression equation consists the arrangement of all the process parameter according to their level and corresponding coefficient term expressed in equation 3.

$$\text{Diameter}=5.6610 - 0.0614 (T1)- 0.0994 (T2) + 0.1608 (T3) +0.0143 (S1) + 0.0052 (S2)- 0.0194 (S3) + 0.0030 (F1) - 0.0206 (F2) + 0.0176 (F3) \quad (3)$$

**Perpendicularity**

Perpendicularity in drilled holes is defined as the axis of the hole being exactly 90 degrees (normal) to the workpiece's reference surface or plane. This means that the hole should be drilled so that its axis is perfectly perpendicular to the material's surface or base. Perpendicularity is an important geometric characteristic, especially for holes that must fit or align with other components, such as pins, shafts, or bearings, which require precise orientation [37]. The key elements include drill bit misalignment, machine deflection, tool wear, improper fixturing, vibration, and uneven material properties. Perpendicularity is commonly measured using high-precision instruments.

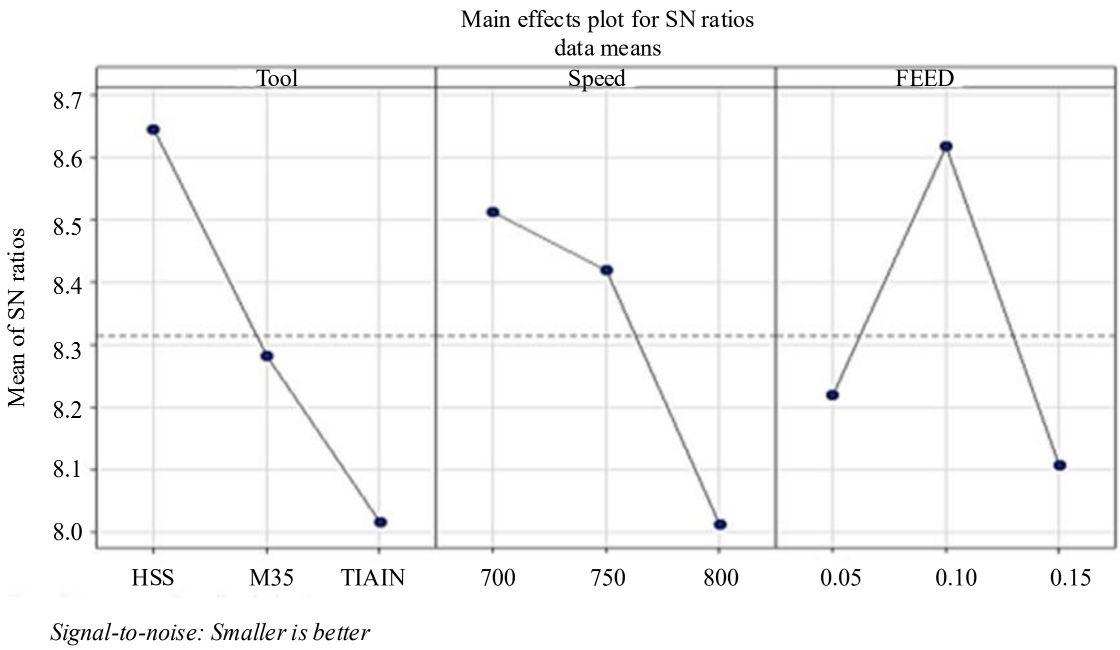


**Figure 6.** Main effects plot for S/N ratio of perpendicularity

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Perpendicularity is the primary response factor in determining the quality of drilled holes. To evaluate the effect of process parameters on perpendicularity, computed means and S/N ratios for each factor are computed. To maximize perpendicularity, the S/N ratio was determined based on the criterion "smaller is better." The S/N ratio is used in the Taguchi technique to calculate the quality characteristics' departure from the desired value. The S/N ratio is used to calculate the means of the response values at each parameter level, as shown in Figure 6.

The ANOVA test results proved that, no parameter got significant value, all its P-Values are more than 5% and the feed rate is measured as 0.088, is somewhat close to 5%, but it is not got significant. The perpendicularity value is varying between 0.3341 to 0.4217. The minimum value is 0.3341 and maximum value is 0.4217. The estimated F and P values of the drill parameters are tabulated in Table 8. The measured values clearly showed that, all the perpendicularity values are having very close values.

**Regression Equation**

The regression equation consists the arrangement of all the process parameter according to their level and corresponding coefficient term expressed in equation 4.

$$\text{Perpendicularity} = 0.3847 - 0.0136(T1) + 0.0006\,(T2) + 0.0130(T3) - 0.0093\,(S1) - 0.0037\,(S2) + 0.0130\,(S3) + 0.0042\,(F1) - 0.0130\,(F2) + 0.0088\,(F3) \quad (4)$$

**Surface Roughness**

Surface roughness in drilled holes refers to the microscopic irregularities and texture created by the drilling process. It is an important quality feature in manufacturing, particularly for parts that require precise fits, smooth operation, or optimal performance in terms of wear resistance, sealing, or friction [38]. Surface roughness in drilled holes is determined by a number of factors, including the cutting tool used, drilling parameters, material properties, and the overall machining process. The roughness of a hole's surface can have an impact on how well mating parts fit, how durable the hole is, and its ability to retain lubricants or resist corrosion. Surface roughness is mainly determined by drill bit type, cutting speed (RPM), feed rate, drilling depth, tool wear, material type, coolant or lubrication, chip removal, tool geometry, and peck drilling. Surface roughness is measured as Ra (Arithmetic Average Roughness): Rz (Average Maximum Height of the Profile): Rq (Root Mean Square Roughness) using Surface Profiling Instruments.

Surface roughness can be improved by reaming or boring, optimizing cutting conditions, selecting the right tool, cooling and lubricating, controlling tool wear, employing precision drilling machines, and peck drilling for deep holes. Surface roughness is the primary response element in determining the quality of drilled holes. To assess the influence of process parameters on surface roughness, computed means and S/N ratios for each factor are created. To optimize surface roughness, the S/N ratio was calculated using the "smaller is better" criterion. In the Taguchi technique, the difference between the desired value and quality characteristics is calculated using the signal-to-noise (S/N) ratio. The means of the response values are determined at the parameter level shown in Figure 7 using the S/N ratio.

**Table 8.** ANOVA results of perpendicularity.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Drill Material | 2 | 0.26069 | 0.13034 | 5.93 | 0.144 |
| Spindle Speed | 2 | 0.14220 | 0.07110 | 3.24 | 0.236 |
| Feed Rate | 2 | 0.45486 | 0.22743 | 10.35 | 0.088 |
| Error | 2 | 0.04395 | 0.02198 | | |
| Total | 8 | 0.90170 | | | |

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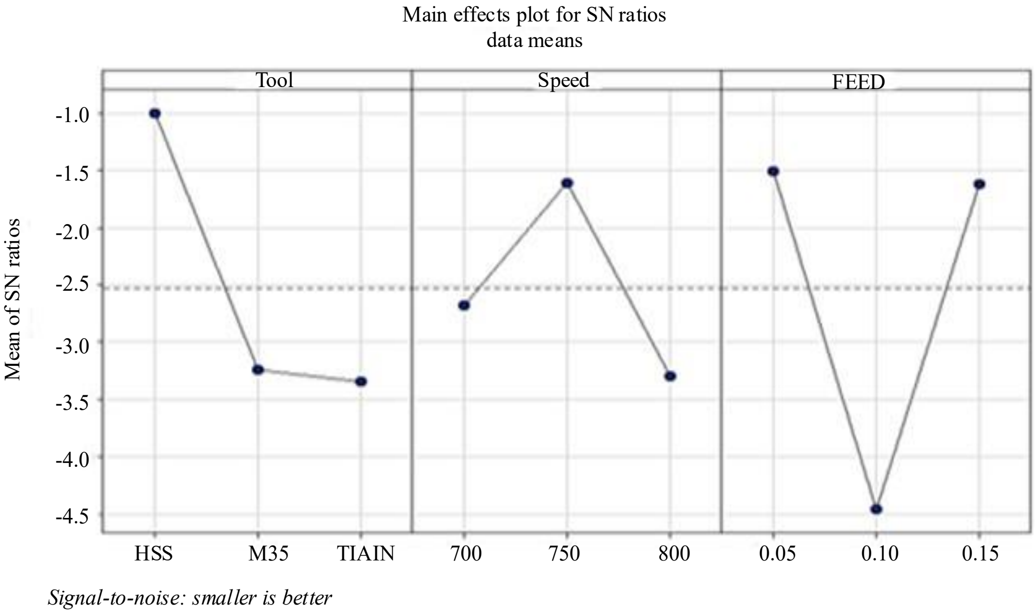


**Figure 7.** Main effects plot for S/N ratio of surface roughness (Ra)

**Table 9.** ANOVA Results of Surface Roughness

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Drill Material | 2 | 0.001068 | 0.000534 | 0.37 | 0.732 |
| Spindle Speed | 2 | 0.000811 | 0.000406 | 0.28 | 0.783 |
| Feed Rate | 2 | 0.000791 | 0.000395 | 0.27 | 0.787 |
| Error | 2 | 0.002921 | 0.001461 | | |
| Total | 8 | 0.005591 | | | |

**Table 10.** Predicted Values for Roundness, Cylindricity, Diameter, Perpendicularity From Regression Equations.

| Hole no. | Roundness | Cylindricity | Hole diameter | Perpendicularity | Surface Roughness | | |
|---|---|---|---|---|---|---|---|
| | | | | | *Ra* | *Rq* | *Rz* |
| 1 | 0.0184 | 0.04205 | 5.6685 | 0.37115 | 1.004 | 1.239 | 4.977 |
| 2 | 0.0197 | 0.0487 | 5.659 | 0.3847 | 1.366 | 1.663 | 7.290 |
| 3 | 0.0211 | 0.05535 | 5.6495 | 0.39825 | 1.029 | 1.241 | 4.768 |
| 4 | 0.0179 | 0.0449 | 5.676 | 0.3735 | 1.721 | 2.155 | 8.813 |
| 5 | 0.0192 | 0.05155 | 5.6665 | 0.38705 | 1.164 | 1.534 | 7.096 |
| 6 | 0.0221 | 0.04965 | 5.6345 | 0.39355 | 1.528 | 1.929 | 7.802 |
| 7 | 0.0174 | 0.04775 | 5.6835 | 0.37585 | 1.461 | 1.815 | 7.324 |
| 8 | 0.0202 | 0.04585 | 5.6515 | 0.38235 | 1.095 | 1.317 | 5.341 |
| 9 | 0.0216 | 0.0525 | 5.642 | 0.3959 | 1.984 | 2.548 | 10.880 |
| Avg | 0.0197 | 0.04869 | 5.659 | 0.3847 | 1.372 | 1.715 | 7.143 |
| | 0.0127 | 0.0481 | 5.6610 | 03847 | | | |

The ANOVA test results revealed that no parameter had a significant value, and all of their P-values were greater than 5%. The surface roughness value (Ra) ranges from 1.004 to 1.984. The minimum value is 1.004, and the maximum is 1.984. Table 9 presents the estimated F and P values for the drill parameters. The measured values clearly demonstrated that all surface roughness values were quite near.

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**Regression Equation**

The regression equation consists the arrangement of all the process parameter according to their level and corresponding coefficient term expressed in equation 5.

$$Ra\ (\mu m)= 1.3724 - 0.2394\ (T1) + 0.0986\ (T2) + 0.1409\ (T3) + 0.0229\ (S1) - 0.1641\ (S2) + 0.1412\ (S3)\ 0.1634\ (F1) + 0.3179\ (F2) - 0.1544\ (F3) \quad (5)$$

In general, the findings indicate that speed is the most influential factor in achieving optimal roundness, cylindricity, diameter, and perpendicularity. According to the regression equations, speed and feed impact roundness and diameter in the opposite direction, while cylindricity and perpendicularity are affected in the same way.

## CONCLUSION

The peck drilling approach was used to analyze the deep hole drilling properties of AISI 316 alloy, and it revealed substantial benefits such as enhanced material removal rates, reduced tool wear, improved surface polish, and improved dimensional accuracy.  Following the examination of the measured results, the following conclusions were made.

The peck drilling method is successfully used to making deep hole drills.

i. The outcomes like, Roundness, surface roughness, cylindricity, hole diameter and perpendicularity of the holes are studied and analysed.
ii. The hole diameter and cylindricity outcomes are got significant, proved with ANOVA analysis.
iii. The lowest roundness value was found using M35 tool at 800 rpm and a feed rate of 0.05mm/rev and using TiAlN tool at 700rpm and a feed rate of 0.15mm/rev. Cylindricity is within a minimum of 0.02 for holes 4,5, and 6 machined by M35 drill bit and it is within 0.04 for holes machined with HSS drills.
iv. The surface roughness according to the Ra, is measured as 1.004, Rq value is measured as 1.239 and Rz value is measured as 4.977, all these conditions are concerned with sample 1.
v. The predicted values show the close agreement among the values and the error is less than 10% observed from all the outcomes.

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**Competing Interests**

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## REFERENCES

1. D. Biermann, F. Bleicher, U. Heisel, F. Klocke, H.-C. Möhring, A. Shih, “Deep hole drilling”, CIRP Annals, Volume 67, Issue 2, 2018, pp:673-694, https://doi.org/10.1016/j.cirp.2018.05.007.
2. M. Ramachandran, Vishal Fegade, U. Ragavendran, “Parameters optimisation for drilling of austenitic stainless steel by Taguchi method using desirability function analysis”, https://www.researchgate.net/publication/321033640.
3. N.S. Patel, Priyansh L. Parihar, Jay S. Makwana, “Parametric optimization to improve the machining process by using Taguchi method: A review”, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.03.005.
4. Saurin Sheth, P.M. George, “Experimental investigation, prediction and optimization of cylindricity and perpendicularity during drilling of WCB material using grey relational analysis”, http://dx.doi.org/10.1016/j.precisioneng.2016.01.002
5. Asif Khan, Qaiser Saghir, Ali Raza, “Determining the effects of selected cutting parameters on Circularity and Cylindricity in turning operations for steel 4140 using Taguchi methods”, Electronic Research Journal of Engineering, Computer and Applied Sciences www.erjsciences.info Volume 1 (2019).

© STM Journals 2025. All Rights Reserved 

6. Siddiquee, A.N., Khan, Z.A., Goel, P., Kumar, M., Agarwal, G. and Khan, N.Z., 2014. Optimization of deep drilling process parameters of AISI 321 steel using Taguchi method. Procedia Materials Science, 6, pp.1217-1225.
7. Sharma, K., Kumar, G. and Kumar, M., 2021, May. Application of taguchi method coupled with GRA for optimization of drilling process parameters. In IOP Conference Series: Materials Science and Engineering (Vol. 1149, No. 1, p. 012032). IOP Publishing.
8. S. P. Sundar Singh Sivam, Ganesh Babu Loganathan, K. Saravanan, S. Dinesh Guhan, and Aishik Banerjee, "Effects of Drilling Process Parameters Using ANOVA and Graphical Methods", Advances in Materials Research, Springer Proceedings in Materials 5, https://doi.org/10.1007/978-981-15-8319-3_35.
9. Tarakeswar Barik, Sourav Kumar Jena, Shivraj Gahir, Kamal Pal, Sanat Kumar Pattnaik, "Process parametric optimization in drilling of CFRP composites using GRA method", Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.04.220.
10. KM, Alagappan, Vijayaraghavan S, and Jenarthanan MP., 2020. "Optimization of process parameters on drilling of natural fibres reinforced in epoxy resin matrices using Taguchi–Grey relational analysis." Multidiscipline Modeling in Materials and Structures 16(5): 937-949.
11. C Sarala Rubi, J Udaya Prakash and C Rajkumar, "Optimization of Process Parameters using Taguchi Technique for Drilling Aluminium Matrix Composites (LM6 / B4C)", IOP Conf. Series: Materials Science and Engineering 912 (2020) 032016 IOP Publishing doi:10.1088/1757-899X/912/3/032016.
12. Damavandi, E., Kolahdooz, A., Shokoohi, Y., Rostami, S.A.L. and Tabatabaei, S.M., 2021. Multi-objective parameter optimisation to improve machining performance on deep drilling process. International Journal of Machining and Machinability of Materials, 23(5-6), pp.500-513.
13. Turgay Kıvak, Gurcan Samtas, Adem Cicek, 2012, Taguchi method-based optimization of drilling parameters in drilling of AISI 316 steel with PVD monolayer and multilayer coated HSS drills. Measurement 45 (2012) 1547–1557, doi:10.1016/j.measurement.2012.02.022.
14. M. Balaji, B.S.N. Murthy, N. Mohan Rao, Optimization of Cutting Parameters in Drilling of AISI 304 Stainless Steel Using Taguchi and ANOVA. Procedia Technology 25 (2016) 1106 – 1113.
15. Josef Sedlak, Jan Zouhar, Stepan Kolomy, Martin Slany & Emil Necesanek, Effect of high-speed steel screw drill geometry on cutting performance when machining austenitic stainless steel, Scientific Reports, (2023) 13:9233, doi:10.1038/s41598-023-36448-y.
16. R. Hari Nath Reddy, Mathew Alphonse, V.K. Bupesh Raja, K. Palanikumar, D.R. Sai Krishna Sanjay, K.V. Madhu Sudhan, "Evaluating the wear studies and tool characteristics of coated and uncoated HSS drill bit – A review", Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.02.022.
17. Aseel Jameel Haleel, "Optimization Drilling Parameters of Aluminum Alloy Based on Taguchi Method", Al-Khwarizmi Engineering Journal, Vol.14, No.2, P.P.14-21 (2018) https://doi.org/10.22153/kej.2018.12.001.
18. Güven Meral & Murat Sarıkaya & Mozammel Mia & Hakan Dilipak & Ulvi Şeker, "Optimization of hole quality produced by novel drill geometries using the Taguchi S/N approach", The International Journal of Advanced Manufacturing Technology, https://doi.org/10.1007/s00170-018-2956-z.
19. R. Ramesh Babu, R. Karthick, P. Sabarinathan, R. Shyam Sundar, C. Pradeep, "OPTIMIZATION OF DRILLING PARAMETERS OF SS304 BY TAGUCHI METHOD", International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 01 | Jan 2019.
20. A. Z. Sultan[a], Safian Sharif, Denni Kurniawan, "Effect of Machining Parameters on Tool Wear and Hole Quality of AISI 316L Stainless Steel in Conventional Drilling", Procedia Manufacturing 2 (2015) 202 – 207, doi:10.1016/j.promfg.2015.07.035.
21. Cogorno, G.R., 2006. Geometric dimensioning and tolerancing for mechanical design. McGraw-Hill Publishers.
22. Prof. Dr.-Eng. J.Chajda, Dr.-Eng. M.Grzelka, MSc.-Eng. B.Gapinski, MSc.-Eng. M. Pawłowski, MSc.-Eng. M.Szelewski, Dr.-Eng. M. Rucki, "Coordinate measurement of complicated parameters like roundness, cylindricity, gear teeth or free-form surface" 8 INTERNATIONAL CONFERENCE ADVANCED MANUFACTURING OPERATIONS, https://doi.org/10.5109/4843108.

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23. K. Giasin, "The effect of drilling parameters, cooling technology, and fiber orientation on hole perpendicularity error in fiber metal laminates" The International Journal of Advanced Manufacturing Technology (2018) 97:4081–4099, https://doi.org/10.1007/s00170-018-2241-1.
24. Rahul Tukaram Bhole, Prof R. S. Shelke, "Optimization of Drilling Process Parameters for AISI 316L by Using Taguchi Method" International Journal of Scientific Research in Science, Engineering and Technology, 2 (4), pp.100-106.
25. A. Pramanik, A. K. Basak, M. N. Islam, Y. Dong, Sujan Debnath and Jay J. Vora, "Optimization of Accuracy and Surface Finish of Drilled Holes in 350 Mild Steel", Optimization of Manufacturing Processes, Springer Series in Advanced Manufacturing, https://doi.org/10.1007/978-3-030-19638-7_3.
26. Sheth, S., Chauhan, P., Modi, B.S. and Pancholi, A., 2014. Study and investigate effect of cutting parameters in drilling on cylindricity and perpendicularity. In Proceedings of the fourth national conference on recent advances in manufacturing (RAM-2014), SVNIT, Surat, Vol. 1, pp. 43-48.
27. Yavuz, M. et al., 2020. Investigation of the effects of drill geometry on drilling performance and hole quality. The International Journal of Advanced Manufacturing Technology, 106, pp.4623-4633.
28. M. Balaji, B.S.N. Murthy, N. Mohan Rao, "Optimization of Cutting Parameters in Drilling of AISI 304 Stainless Steel Using Taguchi and ANOVA", Procedia Technology 25 (2016) 1106 – 1113, doi: 10.1016/j.protcy.2016.08.217.
29. Hamza A. et al., "Evaluation of Cutting-Tool Coating on the Surface Roughness and Hole Dimensional Tolerances during Drilling of Al6061-T651 Alloy", Materials 2021, 14, 1783. doi:10.3390/ma14071783.
30. Deng, CS., Chin, JH. Hole roundness in deep-hole drilling as analysed by Taguchi methods. *Int J Adv Manuf Technol* 25, 420–426 (2005). https://doi.org/10.1007/s00170-003-1825-5.
31. Bronis, M.; Krawczyk, B.; Legutko, S. Effect of Choice of Drilling Kinematic System on Cylindricity Deviation, Roundness Deviation, Diameter Error and Surface Roughness of Holes in Brass Alloy. *Processes* 2024, *12*, 220. https://doi.org/10.3390/pr12010220.
32. R A Rashid, M N Murad, R Hamidon, S Shariffuddin and M A M Ali, Experimental investigation of machining parameter on hole quality in drilling Ti-6Al-4V, IOP Conf. Series: Materials Science and Engineering 932 (2020) 012128, doi:10.1088/1757-899X/932/1/012128.
33. Ming Li, Wei Tian, Junshan Hu, Changrui Wang, Wenhe Liao, Effect of hole perpendicularity error and squeeze force on the mechanical behaviors of riveted joints, Microsc Res Tech. 2021;1–14. DOI: 10.1002/jemt.23977.
34. Zeman, O.; Schwenn, M.; Schorn, J.; Bergmeister, K. Statistical Evaluation of the Perpendicularity of Boreholes in Concrete for Post-Installed Fasteners. *Civil Eng* 2020, *1*, 253-263. https://doi.org/10.3390/civileng1030016
35. Meral, G., Sarıkaya, M., Mia, M. *et al.* Optimization of hole quality produced by novel drill geometries using the Taguchi *S*/*N* approach. *Int J Adv Manuf Technol* 101, 339–355 (2019). https://doi.org/10.1007/s00170-018-2956-z.
36. Ayllon, Jorge, et al. "An Analysis of the Circularity of the Holes in the Drilling of Basalt Fiber Reinforced Laminates." Key Engineering Materials, vol. 960, Trans Tech Publications, Ltd., 10 Oct. 2023, pp. 73–80. Crossref, doi:10.4028/p-6g9its.
37. Sedlak, J., Zouhar, J., Kolomy, S. *et al.* Effect of high-speed steel screw drill geometry on cutting performance when machining austenitic stainless steel. *Sci Rep* 13, 9233 (2023). https://doi.org/10.1038/s41598-023-36448-y.
38. Pradeep K. Singh, Kanish Kumar, Pardeep Saini, Optimization of surface roughness and hole diameter accuracy in drilling of EN-31 alloy steel – A TGRA based analysis, Volume 26, Part 2, 2020, Pages 2961-2971, https://doi.org/10.1016/j.matpr.2020.02.611.

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