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Effects of machining parameters on H13 die steel using CNC drilling machine

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Abstract

In order to enhance the fitness of the product and in order to improve productivity in turning operations, greater amount of challenges have been faced. In this paper, we have made a comparative analysis of HSS and carbide coated HSS drills while machining with H13 steel plates. For the drilling operation, process parameters were analysed using the Taguchi design of experiments. The response performance characteristics of surface roughness of H13 die steel plates for the drilling settings, cutting speed (rpm), and feed rate (mm/min) is optimized. The design of the experiment was conducted using the Taguchi technique for the L18 orthogonal array, and an analysis of variance was observed. The effect of drilling settings on the quality of drilled holes is examined; variation in surface roughness for various levels of speed and feed and the different combinations of these levels will form an L18 orthogonal array design of experiment by Taguchi analysis. A total of 36 cutting tests were performed with two different drill bits; here three different cutting speeds of 300, 600, and 900 rpm were taken with a feed rate of 0.02, 0.04, and 0.06 mm/rev combinations. The response of SN ratio for surface roughness of HSS and carbide tool has been found out for different levels of speed and feed. From this Taguchi analysis, it is identified that the optimal parameter. As a result, the factors are analysed, and optimized parameters have been concluded for H13 material using HSS, and carbide tools were examined both statistically and experimentally. The carbide coated drill bit gives 60% better surface roughness value based on experimental data obtained. The surface roughness value based on experimentation for HSS tool was found to be 34.16% and carbide coated drill bit was 23.40%.

Keywords

H13 steel plate, Taguchi design of experiment, grey relation analysis, SN ratio, ANOVA

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Introduction

Shear deformation of the work material is the most common cutting action in machining, and it leads to the generation of numerous types of chips. While removal of chips, a new surface is revealed, which is referred to as the machined surface. The response performance characteristic of the surface roughness of H13 die steel plates is used to improve the drilling parameters, which include two factors such as cutting speed (rpm) and feed rate (mm/rev) An attempt has been made to optimize the drilling parameters using Taguchi's technique, which is based on the robust design.[1] Experiments are carried out on machining the various % volume of Si3*N*4 in epoxy Si3*N*4 composite materials, using the HSS tool for various cutting conditions and the diameter of the drill bit.[2,36,37] The results revealed that the combination of factors and their levels A2B3C2D1, that is, the machining is done in the presence of cutting fluid at a speed of 500 rpm. With a feed of 0.04 mm/s and hole-depth of 25 mm yielded the optimum, that is, minimum surface roughness.[3] The optimization of the machining process with numerous performance criteria for raising the standard of the drilled holes is made simpler by the combination of Grey Relational Analysis and Taguchi analysis.[4] The combination of a 25-degree helix angle, a feed rate of 12 mm per minute, and a spindle speed of 800 r/min results in cutting settings that are optimal for surface roughness. The combination of a 25-degree helix angle, a feed rate of 10 mm/min, and a spindle speed of 600 r/min results in cutting conditions that accelerate vibration to the greatest extent.[5,7,8] The most important component affecting the surface roughness was the cutting tool, which contributed 39.14%, while the most important factor determining the thrust force was the feed rate, which contributed 82.77%.[6] The most important parameters that determine surface roughness are feed rate and spindle speed; however, using abrasive slurry has resulted in an overall improvement of about 11% in surface roughness.[9]

The most important parameters that influence surface roughness are feed rate and spindle speed. However, the abrasive slurry has been shown to improve surface roughness overall by about 11%.[10,11] Delamination during post-assembly can be decreased by reducing die and mould thickness. The copper thickness has no effect on the energy release rate.[12,13] Uncoated drills caused less delaminating than TiN and TiAlN-coated HSS drills, and optimum cutting parameters were determined as the high cutting speed, low feed rate, and drill point angle combination.[14,15] In this paper, the effects of the two input process parameters such as spindle speed, feed rate on surface roughness using carbide coated drill and HSS drill bit to determine optimum machining conditions on H13 die steel. The experiments were carried out in CNC Vertical Machining Centre. For this purpose, the experiments were done according to the Taguchi L9 orthogonal array, and comparative analysis of L18 orthogonal array designed and optimal parameters found out. The effect levels on the surface roughness of the control factors with analysis of variance (ANOVA) performed using the experimental results were determined. Experiments were carried out via the L_{18} orthogonal array. Control factors for optimum surface roughness (Ra) values were determined by using the Taguchi method. Two different grinding wheels, three different cryogenic samples, and three different depths of cuts were selected as control factors. The optimum values for the surface roughness were found to be a point angle of 118°.[16,17] The surface roughness parameters were investigated using two drill bits with three different feed and speed, and the results were examined both experimentally and statistically.[18]

Cutting force (Fc) and study of the machined surface in turning of AA 6061 alloy with uncoated and PVD-TiB2 coated cutting inserts have been the main topics of research. On a CNC turning with dry cutting, turning experiments have been undertaken. The outcomes showed that an uncoated insert produced the greatest results in terms of Fc and Ra. Moreover, the feed rate has the greatest impact on Ra and Fc.[19] The most important independent factors that affected delamination on GFRPs were feed rate and tool material. Moreover, less delamination thrust force is produced by ultrasonic and vibration-assisted drilling procedures than by conventional drilling. Kavad B V et al. (2014)[20] discovered that cooling techniques had an impact on the temperature of the drill flank and the risk of GFRP damage. They used RSM to explore the various parameters and found that increasing the feed rate while maintaining the speed raises the drill temperature while maintaining the damage factor. However, increasing the feed rate while maintaining a fixed spindle speed raises the damage factor and drill temperature.[21,32] The specimen with uncoated twist drills produces the greatest quality products with less delamination and tool wear, according to research using titanium aluminium nitride coated twist drills.[22] Findings indicate that materials thickness, not fibre orientation or feed rate, has the greatest influence on peel-up delamination. Therefore, feed rate has the greatest impact on push-down delamination. Further research revealed that push-down laminates had a more significant impact than peel-up laminates.[23,35]

Drilling while accounting for cutting forces was used to evaluate the delamination on carbon fibre reinforced composites. According to the authors' analysis of three different drilling techniques – conventional, orbital, and circular drilling – delamination values at higher feed rates during the circular drilling process are relatively very low compared to those at lowest feed rates for orbital and conventional drilling. By maximising the tool geometry parameters, polymer composites with carbon reinforcements were created and a study of drilling operation delamination and cutting forces was conducted. They have determined that reducing the feed rate and nominal feed of cut when drilling, particularly with reamer and brad drill bits, reduces delamination.[24] Less damage occurs during delamination when drilling CFRP with a helical drill bit operating at its maximum cutting speed. Also, authors claimed that the Reamer drill bit is best for drilling CFRP composites with the least amount of delamination based on their experimental findings. Feito et al.,[25] Mohan et al.,[38] and Sunny et al.,[39] worked on drilling in GFRP while experimenting with different machining parameters to determine how they affected torque, push out, peel ups, and other factors. Because the epoxy polymer matrix has a low thermal conductivity, they have found that the pre-increment of wear causes an increase in surface roughness because heat is produced. Artificial neural networks and multivariable regression models are used to assess the bearing capacity of drilled holes.[26] Studying the impact of the silicon nitride content (Si3*N*4) on epoxy composite drilling characteristics led researchers to identify Si3*N*4 as the main cause of circularity, surface roughness, and cylindricity.[27] Drilling was done on polypropylene GFRP composites using three different types of tools, and the results showed that increasing feed rate results in an increase in thrust force, but that the value of thrust force is reduced at higher spindle speed and that using solid carbide and tripped carbide tools results in less delamination damage developing.[28] The smoothness of the drilled surface, as seen by SEM photographs, was another imported observation.[29] The drilling of GFRP composites was evaluated by optimising the drill diameter and other factors, and it was shown that variations in feed rate result in good surface finish and reduced thrust force. Moreover, it is concluded that changing the spindle speed had little to no impact on composites.[30,31] Several failures have developed while drilling composite materials, including delamination, swelling, fibre pullout, edge chipping, and surface roughness.[33,34]

The experiments were carried out with a normal HSS tool, and carbide coated tool with various cutting speeds and feed rates over H13 die steel material. The quality of drill bit has been assessed with respect to H13 die steel. For various degrees of speed and feed, the response of the SN ratio for surface roughness of HSS and carbide tools has been discovered. The ideal parameter is determined by this Taguchi analysis. As a consequence, the variables are reviewed, optimal parameters for H13 material utilising HSS have been determined, and carbide tools have been statistically and experimentally investigated. For multi objective optimization process, Grey Relational Analysis was performed using the following parameters such as spindle speed, feed rate, and drill bit were considered to find the optimum result for MRR and surface roughness.

Materials and methods

H13 die steel is generally a hot work steel which is used for both hot and cold work tooling, and it's basically chromium–molybdenum hot work steel. Repeated heating or repeated cooling cycles in tooling applications while hot work causes thermal fatigue cracking. The hot hardness (hot strength) of H13 is resistant to this. The properties such as excellent heat resistance, wear resistance, high hardness, and ability to withstand thermal fatigue made H13 die steel to find its applications in dies, punches, shaft, axles, and mould components due to its strength to weight ratio. Due to its outstanding combination of extraordinary toughness as well as resistance against thermal fatigue cracking H13 is primarily used for more hot work tooling applications than any other tool steel. They have superior hardenability (due to wide section thickness hardening) and wear resistance than popular alloy steels like 4140.

As illustrated in Tables 1 and 2, the remelting methods increase chemical uniformity, carbide size refinement, and mechanical and fatigue properties. The components that require high toughness are die casting shot sleeves, hot forging dies, extrusion dies, and elastic mould cavities.

H13 die steel is generally hot work steel which is used for both hot and cold work tooling, and it's basically chromium–molybdenum hot work steel. The enhanced thermal wear and cracking produced by repeated heating or cooling processes in a hot work tool and die applications are resistant to H13's recent hardness (hot strength). The incredible mixture of high toughness and thermal fatigue resistance prevents breaking (also called heat cracking). H13 is a tool steel that exceeds other tool steels when it comes to additional hot work in tooling applications. Because of its high hardness and excellent heat treatment durability, the H13 die steel has also been employed in a wide range of cold work tooling applications. Here, H13 has better hardenability and wear resistance than typical alloy steels like H11 and H12.

Machine details

Figure 1 shows the drilling operations performed on an AMS MCV-450 Vertical Milling Centre. The CNC vertical machining centre used here has a multiple spindle speed range of up to 6000 r/min. Table 3 explains the machine configuration. The process parameters that were chosen for testing includes cutting speed in rpm and feed rate in mm/rev.

HSS (high-speed steel) is a tool steel that is more heat resistant and harder than high-carbon steel. They can drill metal, hardwood, and most other materials quicker than carbon steel bits, and they have almost completely replaced carbon steel bits.

Table 1. Mechanical properties of H13 die steel.

Properties	Values
Yield strength	1650 MPa
Brinell hardness	250
Density	7750 kg/m^3
Thermal conductivity	28.6 W/Mk
Modulus of elasticity	215GPa
Rockwell hardness	48

Table 2. Composition of H13 die steel.

Composition	Weight %
Carbon	0.32-0.40
Chromium	5.13-5.25
Iron	89.84-90.41
Silicon	1
Vanadium	1
Nickel	0.3
Copper	0.25
Manganese	0.2-0.5
Phosphorus	0.03
Sulphur	0.03

Figure 1. CNC vertical machining centre.

Table 3. Configurations of VMC.

Specification	Unit	AMS MCV- 450
Table Travel in *X*-Axis	mm	850
Table Travel in *Y*-Axis	mm	400
Headstock travel in *Z*-Axis	mm	550
Table size	mm x mm	1100*450
Maximum load on the table	Kgf	500
Spindle speed	rpm	6000

The selected straight shank type drill bit is made of HSS with total length of 200 mm, shank diameter 10mm, flute length of 145 mm with tip angle 118^o, and with diameter of 10 mm. In high-volume applications, carbide drill bits are extremely effective. Carbide enables extremely fast cutting speeds, long tool life, and the flexibility to work with an extensive range of materials. The cutting edge of the drill bit keeps its efficacy well past that of cobalt and HSS due to carbide's hardness. The selected drill bit is a shank type made of carbide coated of total length 200 mm, shank diameter 10 mm, flute length 145 mm, drill bit diameter 10 mm, and with tip angle of 118^o

Design of experiment

Taguchi method employs a robust test design in order to reduce the variation in a process. The main objective is to offer the maker a good quality product at a competitive cost. The input is given in the form of cutting speed, and feed rate and surface roughness are used as response parameters to describe the drilling process of H13 steel plates. Table 4 demonstrates the L9 orthogonal array design of the experiment with three components and three levels of drilling process parameters. In determining the optimum levels of the control factors, the maximum S/*N* values in the S/N response table generated by the Taguchi method indicate the ideal level of that control factor.[23]

Results and discussion

According to the experiment design, the experiment was carried out on H13 die steel, shown in Figure 2, with different process parameters. The H13 die steel used for experimentation is 80 mm x 80 mm x 6 mm in size. HSS drills and carbide coated drills are used in the drilling process. The SN ratio is used to examine the results of drilling process parameters. Surface roughness testers are used to find the Surface roughness value, and the results are reported in Table 4. The experimentation has been conducted considering two major contributing parameters as per literature, namely cutting speed and feed rate. The cutting speeds opted for investigation are 300, 600, and 900 r/min. Similarly, the feed rates opted for investigation are 0.02, 0.04, and 0.06 mm/rev. Mitutoyo Surface Roughness Tester SJ-410 was used for measuring surface roughness.

Analysis for HSS drill bit

Figure 2 shows H13 steel drilled specimen using an HSS drill bit and Table 5 shows the SN ratio for surface roughness in HSS drills. From Table 4, it is inferred that the highest SN ratio in the table shows the optimum level of each control factor. The SN ratios calculated on the basis of the Ra values obtained as a result of the machining tests performed on the H13 steel according to the Taguchi L9 test design were given in Table 5.

After conducting drilling experiments on H13 steel plates using HSS drill bits, the response table is tabulated. Response Table 6 illustrates the most essential and influential parameters. It suggests that speed is an important factor in obtaining decreased surface roughness in the drilling process while using H13 die steel.

The average SR decreases to 4.997 microns from 5.737 microns (14.81%) with an increase in cutting speed from 300 r/min to 600 r/min. With a further increase in cutting speed to 900 r/min from 600 r/min, the SR has again decreased from 5.737 microns to 3.687 microns which is 35.53%. Similarly, with an increase in feed rate to 0.04 mm/rev from 0.02 mm/rev, the SR reduces from 4.78 microns to 4.120 microns. But, with a further increase in feed rate from 0.04 mm/rev to 0.06 mm/rev, the SR increases by 25.36% from 4.78 microns to 5.52 microns. Design parameters on performance characteristics are determined using ANOVA. The percent contribution ratio of surface roughness is investigated, and the ANOVA conclusion for surface roughness is demonstrated in Table 6. Ninety-five percent confidence level and 5% significance level are considered to find out drilling parameters that affect surface roughness. The value of P must be less than 0.05 for statistically significant on the output control factor, and the value of F, which is the highest, must be considered as the most effective factor. Table 7 reveals that, based on a higher F value, spindle speed is the most important constraint in the drilling operation on H13 die steel plates. The use of carbide coated drill results in a greater surface polish and dimensional tolerance. PCR of A and B factors on the surface roughness reached to be 56.23% and 24.46%, respectively. Cutting speed factor A, 56.23%, was determined as the most significant factor affecting surface roughness.

Figure 3 shows the SN ratio of H13 die steel plates while performing drilling operations. It also shows that the spindle speed at the first level and feed rate at the third level yield lesser surface roughness. So, for producing high-precision, high-toughness dies, the H13 steel plates are ideal. According to this Taguchi study, the best parameter for achieving a smooth surface is 900 r/min at 0.04 mm/rev. Figure 4 shows the change in surface roughness for various speeds and feed rates, as well as the same optimal value for the SN ratio. The validation experiment was conducted, and the results are presented in Table 8.

Table 4. L9 orthogonal array.

Cutting speed	Feed rate
1	1
2	1
3	1
1	2
2	2
3	2
1	3
2	3
3	3

Analysis for carbide coated drill

After conducting drilling experiments on H13 steel plates using carbide coated drill bits, the response table is tabulated. Response Table 9 illustrates the most essential and influential parameters. It suggests that spindle speed is important factors in obtaining decreased surface roughness in the drilling process while using H13 die steel. Figure 5 shows the carbide coated drill bit drilled specimen.

The average SR increases by 0.833 microns from 0.793 microns (4.80%) with an increase in cutting speed from 300 r/min to 600 r/min. With a further increase in cutting speed 600 r/min to 900 r/min, the SR has decreased from

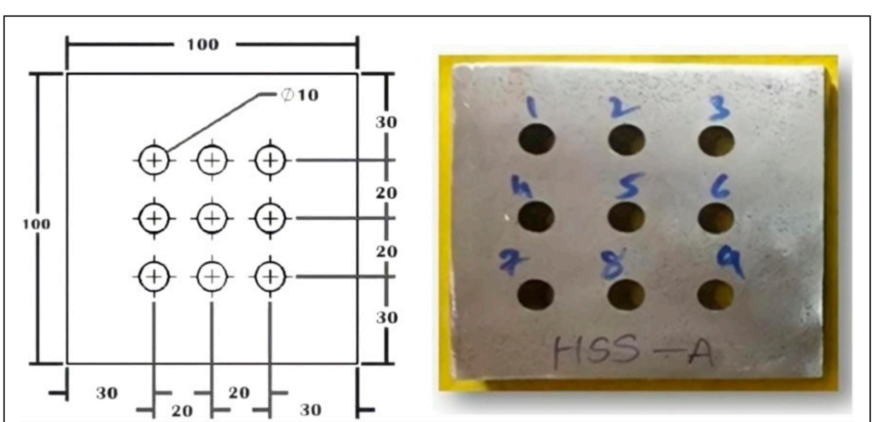

Figure 2. H13 steel drilled specimen (HSS Drill bit).

Table 5. SN ratio for surface roughness in HSS drills.

Cutting speed	Feed rate	Surface finish	SNRA1
rpm	mm/rev	Microns	dB
300	0.02	6.02	15.591
600	0.02	5.12	14.185
900	0.02	3.20	10.103
300	0.04	4.41	13.006
600	0.04	5.01	13.996
900	0.04	2.94	9.366
300	0.06	6.78	16.624
600	0.06	4.86	13.732
900	0.06	4.92	13.892

Table 6. Table for HSS drills response.

LEVEL	Cutting speed	Feed rate
1	-15.07	-13.29
2	-13.97	-12.12
3	-11.1	-14.73
Delta	3.97	2.61
Rank	1	2

0.833 microns to 0.7222 microns which is 15.21%. Similarly, with an increase in feed rate to 0.04 mm/rev from 0.02 mm/rev, the SR increased from 0.733 microns to 0.86 microns. But, with a further increase in feed rate from 0.04 mm/rev to 0.06 mm/rev the SR decreases by 13.65% from 0.86 microns to 0.756 microns.[40–45] Drilling experiments were carried out on H13 steel plates. The significant and influential parameters are represented in response Table 10. It implies that when drilling with H13 die steel, feed is a crucial component in achieving lower surface roughness.

The statistically determinant value for error as 5% is discovered from the F test, according to the above ANOVA analysis in Table 11. According to this research, the feed has a higher value in the F test and is the most dominant element that must be maintained in order to get the desired results. The feed rate contributes 19.26% in achieving the desired SR, followed by cutting speed with 13.14%.

Figure 6 shows the SN Ratio of H13 die steel plates while performing the drilling operation. It also shows that the second level of spindle speed and the second level of feed rate produce lesser surface roughness. The H13 steel plates are ideal for producing high-precision, high-toughness dies. According to this Taguchi study, the best parameter for achieving a smooth

Table 7. Surface roughness in HSS drill ANOVA table.

Variance Source	Degree of Freedom	Sum of Squares	Mean of Squares	F Ratio	*p* value	PCR %
Cutting speed (A)	2	6.579	3.289	5.82	0.065	56.23
Feed Rate (B)	2	2.862	1.431	2.53	0.195	24.46
Error	4	2.260	0.565	-	-	19.31
Total	8	11.700	-	-	-	100

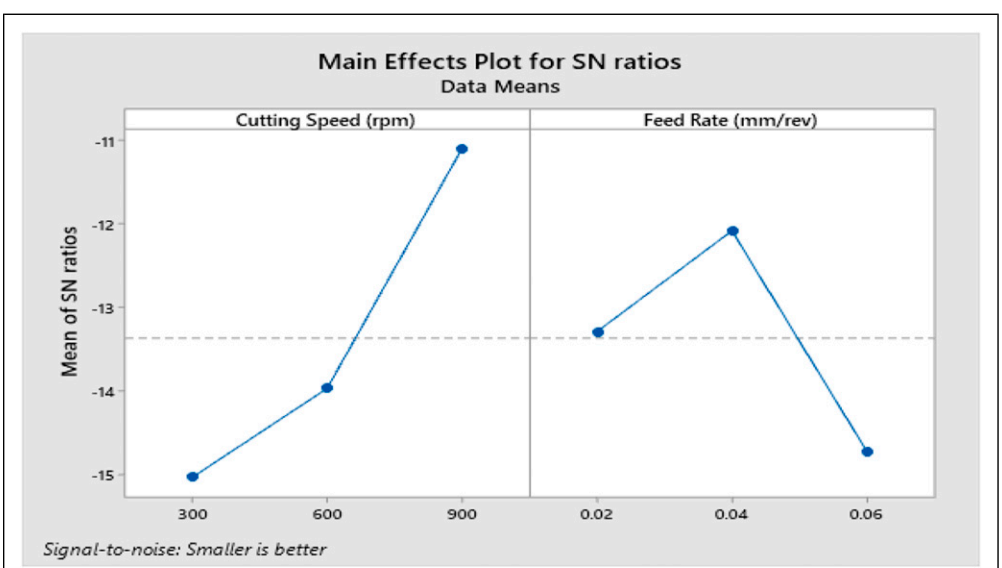

Figure 3. Main effect plot for SN ratios of surface roughness in HSS drill.

surface is 900 r/min at 0.02 mm/rev. Figure 7 shows the variance in surface roughness for various speeds and feed rates, as well as the same optimal value for the SN ratio.[45–47] The validation experiment was conducted, and the results are presented in Table 12. We can see from the plot for SN ratio in Figure 8 that the analysis is based on the assumption that a larger value equals higher surface roughness.

Comparative Analysis of L_{18} orthogonal array

The variation in surface roughness for different levels of speed and feed can be identified in Table 13, and the different combinations of these levels will form an L_{18} orthogonal array design of the experiment using Taguchi analysis.

The signal-to-noise ratio for the various levels of speed and feed can be determined and analysed using the preceding Table 14.

The average SR decreases to 2.915 microns from 3.275 microns (12.35%) with an increase in cutting speed from 300 r/min to 600 r/min. With a further increase in cutting speed from 900 r/min form 600 r/min, the SR has again decreased from 3.275 microns to 2.205 microns which is 32.20%. Similarly, with an increase in feed rate to 0.04 mm/rev from 0.02 mm/rev, the SR reduces from

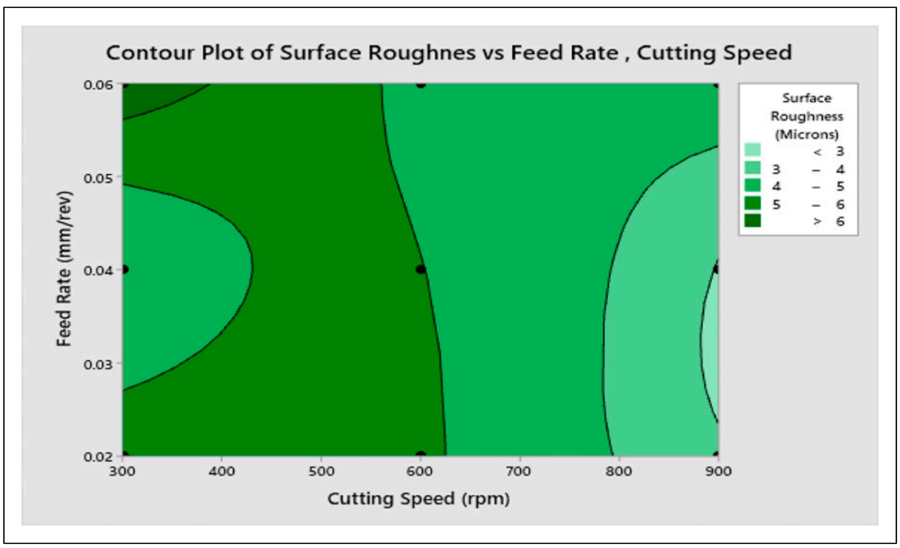

Figure 4. Contour plot of surface roughness versus speed, feed in HSS drill.

Table 8. Validation experiment and its results.

Parameter	Cutting speed (rpm)	Feed rate (mm/rev)	Drill bit	Average value obtained through Experiment	Experimental value	Percentage (%)
SR (Microns)	900	0.04	HSS	4.806	3.164	34.16

Table 9. SN ratio for surface roughness in carbide coated Drill.

Cutting speed rpm	Feed rate mm/rev	Surface finish microns	SNRA1 dB
300	0.02	0.89	15.591
600	0.02	0.82	14.185
900	0.02	0.49	10.103
300	0.04	0.85	13.006
600	0.04	0.89	13.996
900	0.04	0.84	9.366
300	0.06	0.64	16.624
600	0.06	0.79	13.732
900	0.06	0.84	13.892

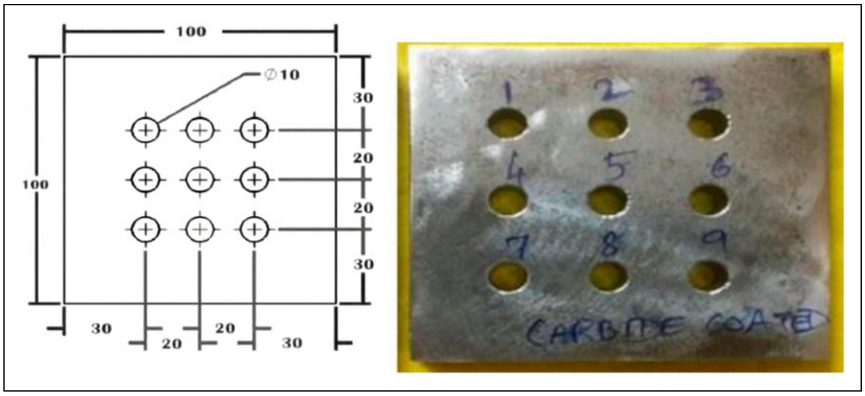

Figure 5. H13 steel drilled specimen (carbide coated drill bit).

Table 10. Table for carbide coated drills response.

LEVEL	Cutting speed	FEED
1	2.100	2.977
2	1.594	1.313
3	3.075	2.479
Delta	1.481	1.665
Rank	2	1

2.756 microns to 2.5 microns. But, with a further increase in feed rate from 0.04 mm/rev to 0.06 mm/rev, the SR increases by 20.34% from 2.5 microns to 3.138 microns. The SR decreases by 514.49% when the coated drill bit is used when compared to the HSS drill bit. We can see from the plot for the SN ratio in Figure 9 that the analysis is based on the assumption that a larger value equals higher surface roughness. According to the Taguchi study, the best parameter for achieving a smooth surface is 900 r/min at 0.02 mm/rev when using carbide coated drill bit.

Figure 9 shows the variance in surface roughness for various speeds and feed rates, as well as the same optimal value for the SN ratio.

From the preceding ANOVA analysis in Table 15, it can be deduced that the statistically determinant value for error is identified as 5% by using the F test. According to this research, the drill bit has a higher value in the F test and is the most important aspect that must be maintained in order to produce the desired outcomes. The feed rate is identified to have more contribution towards obtaining the SR, followed by cutting speed. The feed rate contributes 19.26%, and the cutting speed contributes 13.14%. The p value for both cutting speed and feed rate is 0.086 and 0.379, respectively.

The MRR increases by 46.34% from 0.058 to 0.109 *g*/sec when the cutting speed increase from 300 r/min to 600 r/min. With a further increase in cutting speed to 900 r/min, the MRR has increased by 25.37% from 0.109 to 0.146 *g*/sec. On the other hand, the increase in feed rate has also increased the MRR. An increase of 47.08% is seen with the increase of MRR from 0.058 to 0.111 *g*/sec when the feed rate increases from 0.02 mm/rev to 0.04 mm/rev. When the feed rate is further increased from 0.04 mm/rev to 0.06 mm/rev, the MRR again increases from 0.111 to 0.1445 *g*/sec, which is 23.07% higher than the MRR for 0.02 mm/rev.

The analysis is based on the assumption that a bigger value will result in a higher MRR, as shown in the Figure 10 plot for the SN ratio. According to this Taguchi study, the best parameter for providing a smooth surface with a higher MRR for a carbide coated drill bit is 900 r/min at 0.02 mm/rev. The contour plot in Figure 11 demonstrates the fluctuation in MRR for various levels of speed and feed, with the same optimal value as the SN ratio.

The statistically determinant value for error is discovered as 5% from the F test, according to the above ANOVA analysis in Table 16. From this research, it can be deduced that speed has a greater value in the F test and is the most important component to maintain in order to get the desired results. The cutting speed is identified to have more contribution towards obtaining the MRR, followed by the feed rate. The cutting speed contributes 49%, and the feed rate contributes 46.34%. The p value for both cutting speed and feed rate is <0.0001. A validation experimentation was conducted, and the MRR and SR obtained through that experimentation are as follows in Table 17.

GREY relational analysis in drilling

The fluctuation in MRR and surface roughness for different levels of speed and feed may be identified in Table 18, and the varied combinations of these levels will construct an L18 orthogonal array design of the experiment using Taguchi analysis.

Table 11. Surface roughness in carbide coated drill ANOVA table.

Source	DOF	SS	MS	F	P	PCR (%)
Cutting speed	2	0.01860	0.009300	0.39	0.701	13.14
Feed rate	2	0.02727	0.013633	0.57	0.606	19.26
Error	4	0.09573	0.023933	-	-	67.61
Total	8	0.14160	-	-	-	100.00

Table 19 shows the scenario of GRA for a maximum value of MRR to the minimum value of surface roughness. From Table 19, it is observed the maximum value of MRR is 0.213 for Sl No. 18, and the corresponding surface roughness value is 0.84, and the minimum surface roughness value is 0.49 for Sl No. 12, and the corresponding MRR value is 0.088. The optimized parameter for higher MRR and reduced SR is

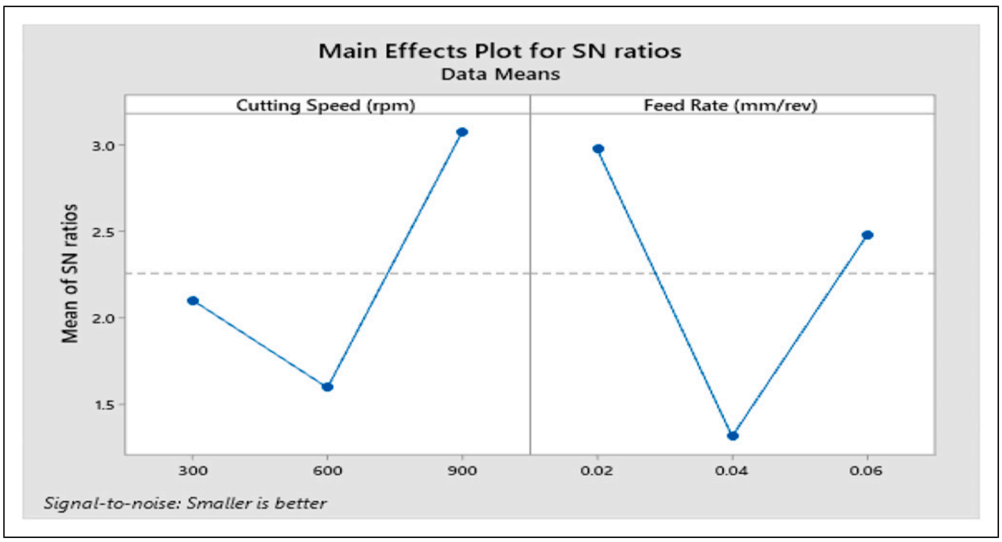

Figure 6. SN ratio Main Effect Plot of surface roughness in carbide coated drill.

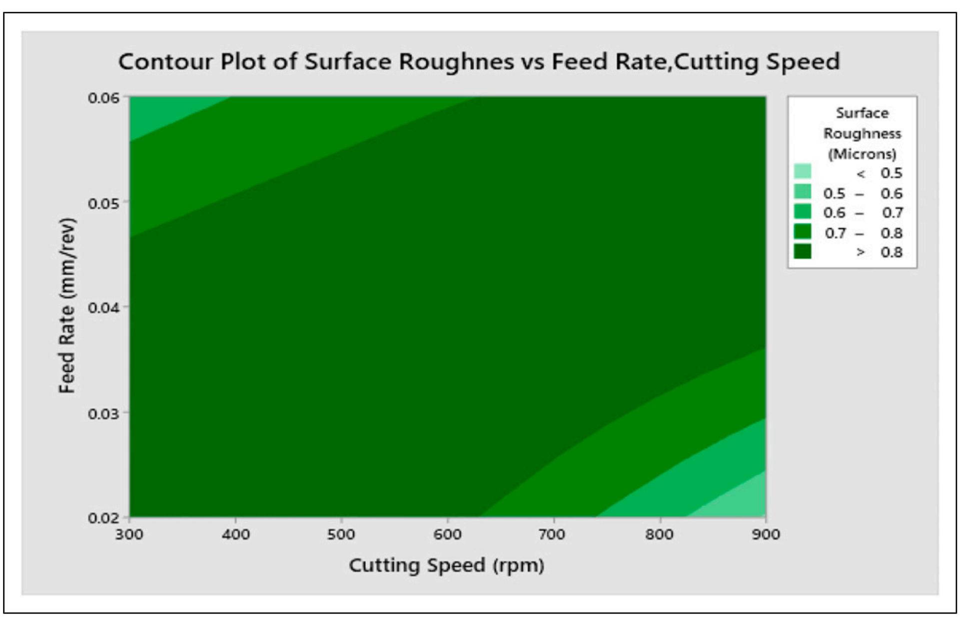

Figure 7. Surface roughness Vs speed, feed in L_{18} analysis for contour plot.

Table 12. Validation for SR using coated drill bit.

Parameter	Cutting speed (rpm)	Feed rate (mm/rev)	Drill bit	Average value obtained through Experiment	Experimental value	Percentage (%)
SR (Microns)	900	0.02	Coated	0.7363	0.564	23.40

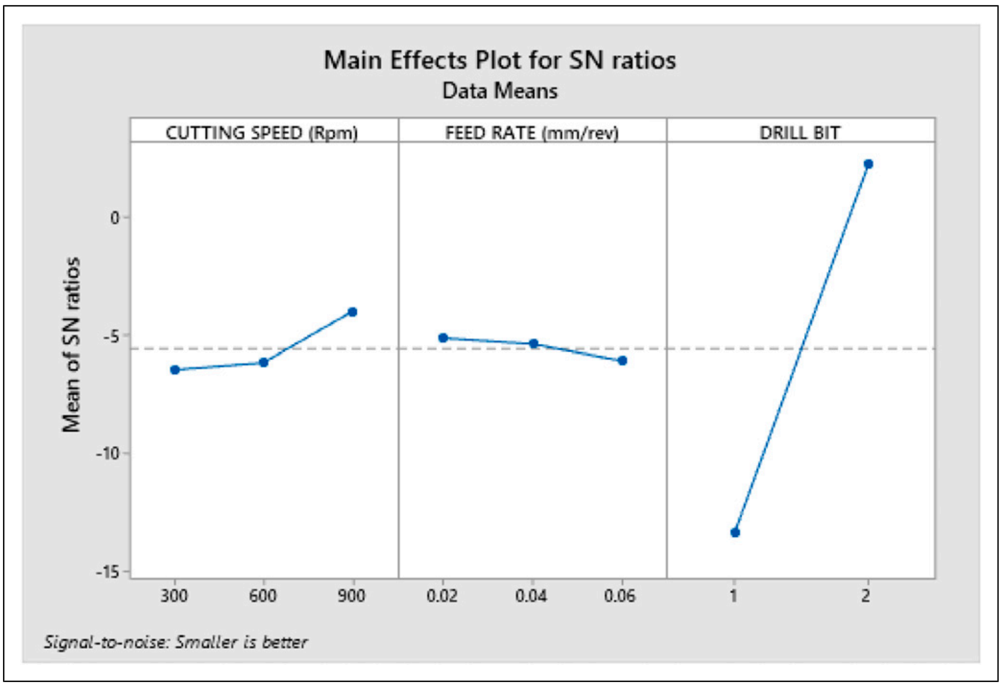

Figure 8. Contour plot of surface roughness versus speed, feed in carbide coated drill.

Table 13. Experimental reading of comparative analysis.

S.No	Cutting speed rpm	Drill bit	Feed rate mm/rev	Surface roughness microns
1	300	1	0.02	6.02
2	600	1	0.02	5.12
3	900	1	0.02	3.20
4	300	1	0.04	4.41
5	600	1	0.04	5.01
6	900	1	0.04	2.94
7	300	1	0.06	6.78
8	600	1	0.06	4.86
9	900	1	0.06	4.92
10	300	2	0.02	0.89
11	600	2	0.02	0.82
12	900	2	0.02	0.49
13	300	2	0.04	0.85
14	600	2	0.04	0.89
15	900	2	0.04	0.84
16	300	2	0.06	0.64
17	600	2	0.06	0.79
18	900	2	0.06	0.84

Table 14. Surface roughness S/N Ratio of comparative analysis.

CUTTING speed rpm	Drill bit	Feed rate mm/rev	Surface roughness microns	SNA1 dB
300	1	0.02	6.02	15.591
600	1	0.02	5.12	14.185
900	1	0.02	3.20	10.103
300	1	0.04	4.41	13.006
600	1	0.04	5.01	13.996
900	1	0.04	2.94	9.366
300	1	0.06	6.78	16.624
600	1	0.06	4.86	13.732
900	1	0.06	4.92	13.892
300	2	0.02	0.89	-1.012
600	2	0.02	0.82	-1.723
900	2	0.02	0.49	-6.196
300	2	0.04	0.85	-1.411
600	2	0.04	0.89	-1.012
900	2	0.04	0.84	-1.514
300	2	0.06	0.64	-3.876
600	2	0.06	0.79	-2.047
900	2	0.06	0.84	-1.514

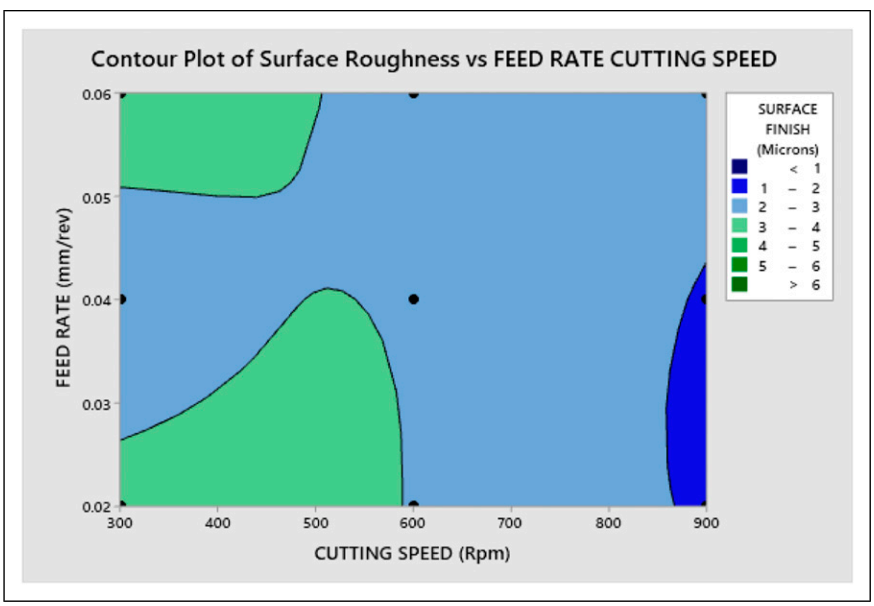

Figure 9. SN ratios main effect plot of surface roughness in L_{18} Analysis.

Table 15. ANOVA Table for comparative surface roughness.

Source	DOF	SS	MS	F	P	PCR (%)
Cutting speed	2	3.557	1.778	3.03	0.086	13.14
Feed rate	2	1.238	0.619	1.05	0.379	19.26
Error	1	73.084	73.084	124.46	<0.0001	67.61
Total	12	7.047	0.587	-	-	100

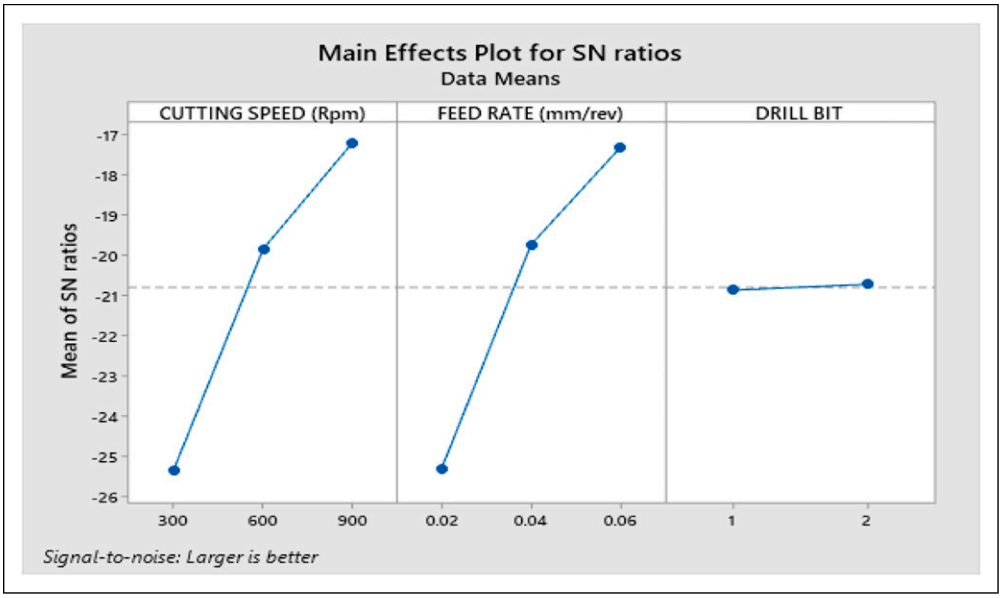

Figure 10. Plot for SN ratio of MRR.

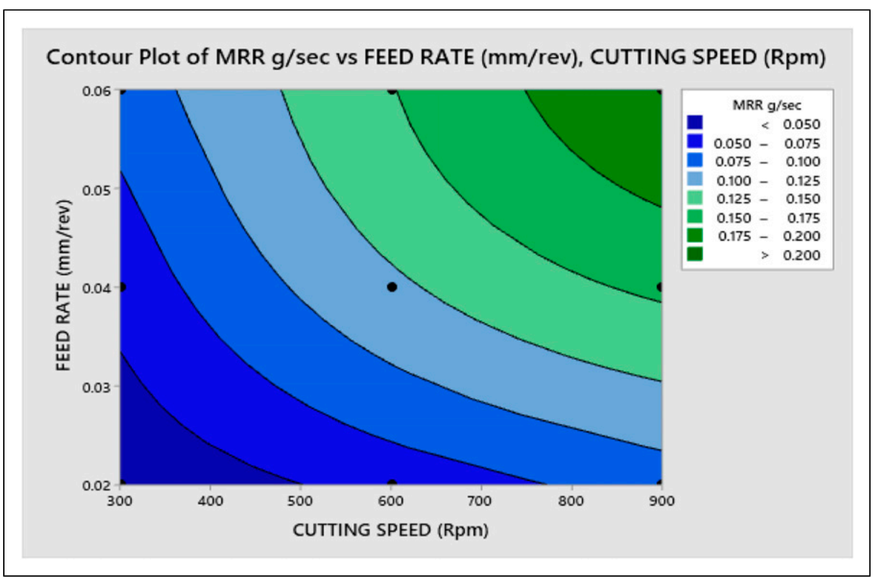

Figure 11. MRR vs. speed and feed for contour plot.

Table 16. ANOVA table for MRR.

SOURCE	DOF	SS	MS	F	P	PCR (%)
Cutting speed	2	0.023533	0.011767	63.52	<0.0001	49.00
Feed rate	2	0.022257	0.011128	60.08	<0.0001	46.34
Drill bit	1	0.000016	0.000016	0.08	0.776	0.03
Error	12	0.002223	0.000185	-	`-	4.63
Total	17	0.048029	-	-	-	100.00

Table 17. Validation experiment and its results.

Parameter	Cutting speed (rpm)	Feed rate (mm/rev)	Drill bit	Average value obtained through Experiment	Experimental value	Percentage
MRR (g/sec)	900	0.06	Coated Drill	0.105	0.125	15.81%
SR (Microns)	900	0.02	Coated Drill	0.125	2.343	-19.42%

Table 18. MRR Reading in HSS Drill.

S.NO	Cutting speed rpm	Feed rate mm/rev	Drill bit	MRR g/sec	Surface roughness microns
1	300	0.02	1	0.029	6.02
2	600	0.02	1	0.059	5.12
3	900	0.02	1	0.086	3.20
4	300	0.04	1	0.059	4.47
5	600	0.04	1	0.122	5.01
6	900	0.04	1	0.158	2.94
7	300	0.06	1	0.088	6.78
8	600	0.06	1	0.149	4.86
9	900	0.06	1	0.185	4.92
10	300	0.02	2	0.033	0.89
11	600	0.02	2	0.059	0.82
12	900	0.02	2	0.087	0.49
13	300	0.04	2	0.059	0.85
14	600	0.04	2	0.118	0.89
15	900	0.04	2	0.151	0.84
16	300	0.06	2	0.084	0.64
17	600	0.06	2	0.149	0.79
18	900	0.06	2	0.212	0.84

900 r/min of cutting speed, 0.06 mm/rev of feed rate, and coated drill bit.

From Figure 12, it is identified that the different levels of speed and feed are analysed and plotted in the graph. The most significant factor is the drill bit with 66.21% of the contribution, and p value is <0.0001. Similarly, the second most significant factor is cutting speed with 20.09%, and the p value is <0.0001. The least significant

Table 19. GRA able MRR analysis.

S.NO	MRR	SR	NMRR	NSR	DEL MR	DEL SR	GRC MRR	GRC SR	GRG	RANK
UNIT	g/sec	Micron								
1	0.029	6.02	0	0.121	1.000	0.879	0.333	0.363	0.348	18
2	0.060	5.12	0.165	0.264	0.835	0.736	0.375	0.405	0.390	16
3	0.087	3.20	0.314	0.569	0.686	0.431	0.422	0.537	0.479	13
4	0.059	4.47	0.163	0.367	0.837	0.633	0.374	0.441	0.408	15
5	0.122	5.01	0.507	0.281	0.493	0.719	0.503	0.410	0.457	14
6	0.159	2.94	0.706	0.610	0.294	0.390	0.629	0.562	0.596	10
7	0.088	6.78	0.323	0	0.677	1.000	0.425	0.333	0.379	17
8	0.149	4.86	0.654	0.305	0.346	0.695	0.591	0.418	0.505	12
9	0.185	4.92	0.850	0.296	0.150	0.704	0.769	0.415	0.592	11
10	0.033	0.89	0.022	0.936	0.978	0.064	0.338	0.887	0.613	9
11	0.060	0.82	0.165	0.948	0.835	0.052	0.375	0.905	0.640	7
12	0.088	0.49	0.319	1.000	0.681	0	0.423	1.000	0.712	4
13	0.059	0.85	0.163	0.943	0.837	0.057	0.374	0.897	0.636	8
14	0.118	0.89	0.485	0.936	0.515	0.064	0.493	0.887	0.690	5
15	0.152	0.84	0.666	0.944	0.334	0.056	0.600	0.900	0.750	3
16	0.084	0.64	0.299	0.976	0.701	0.024	0.416	0.954	0.685	6
17	0.149	0.79	0.654	0.952	0.346	0.048	0.591	0.913	0.752	2
18	0.213	0.84	1.000	0.944	0	0.056	1.000	0.900	0.950	1
MAX	0.213	6.78	1	1	1	1	-	-	-	-
MIN	0.029	0.49	0	0	0	0	-	-	-	-
MAX-MIN	0.184	6.29	-	-	-	-	-	-	-	-

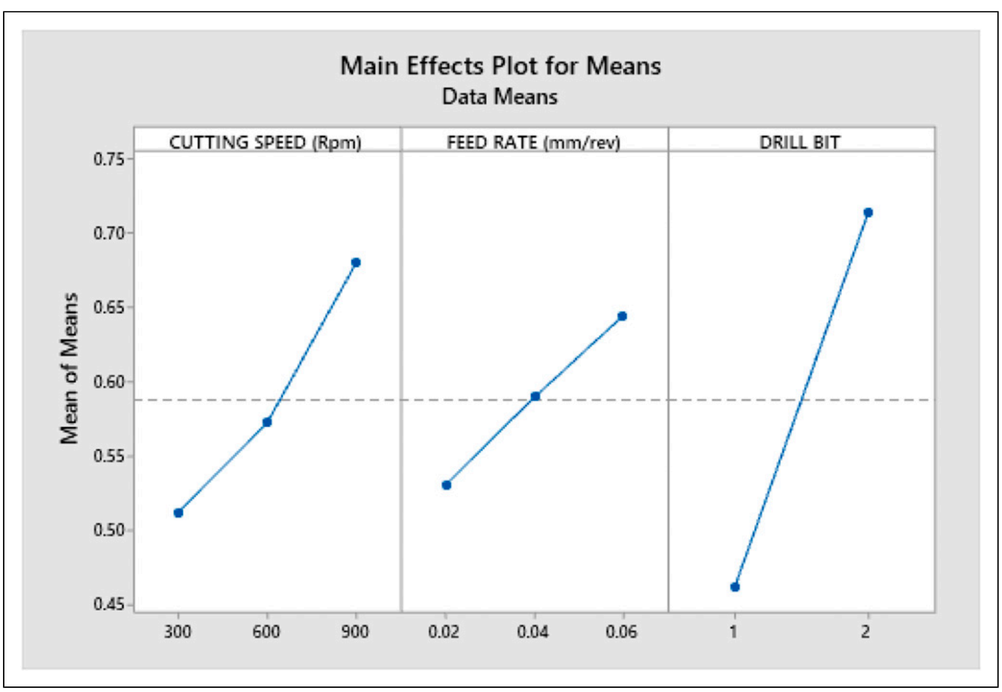

Figure 12. Plot for optimal parameters in GRG analysis.

Table 20. ANOVA for GRG.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PCR (%)
Cutting speed (rpm)	2	0.08719	0.08719	0.043593	25.19	<0.0001	20.09
Feed rate (mm/Rev)	2	0.03867	0.03867	0.019335	11.17	0.002	8.91
Drill bit	1	0.28728	0.28728	0.287282	166.03	<0.0001	66.21
Residual error	12	0.02076	0.02076	0.00173			4.78
Total	17	0.4339					100.00

factor is feed rate which has a p value of 0.002 with an 8.91% contribution. Table 20 shows the ANOVA analysis for GRG.

Conclusions

The speed and feed are variable numerical parameters in the machine, and the drill bit is an arbitrary parameter, according to the analysis of drilling operations in H13 material. The MINITAB Statistical Program was used to conduct the statistical analysis, and the findings were obtained using the Taguchi and ANOVA procedures.

- With a 10mm diameter HSS drill bit in L9 orthogonal, the ideal setting for achieving a flat surface is 900 rpm and 0.02 mm/rev. The validation experiment was conducted, and the SR obtained was 51.90% lesser than the mean value of the SR during experimentation. Cutting speed was found have more significance over SR with 56. 23%, and the second parameter of significance is feed rate, with a 24.46% contribution. Spindle speed was found have more significance over SR with 56. 23%, and the second parameter of significance is feed rate, with a 24.46% contribution.
- Similarly, the optimal settings for achieving a smooth surface when using a 10 mm diameter of carbide coated drill in L9 are 900 rpm and 0.02 mm/rev. The validation experiment was conducted, and the SR obtained was 38% lesser than the mean value of the SR during experimentation. The feed rate contributes 19.26% in achieving the desired SR, followed by cutting speed with 13.14%. The feed rate contributes 19.26% in achieving the desired SR, followed by cutting speed with 13.14%.
- In L18 orthogonal analysis, the ideal parameters for generating a smooth surface with a carbide coated drill bit of 10mm diameter are 900 rpm and 0.02 mm/rev. The feed rate is identified to have more contribution towards obtaining the SR, followed by cutting speed. The feed rate contributes 19.26%, and the cutting speed contributes 13.14%. The P value for cutting speed and feed rate is 0.086 and 0.379, respectively.
- According to this Taguchi study, the best parameter for providing a smooth surface with a higher MRR for a carbide coated drill bit is 900 rpm at 0.02 mm/rev. The cutting speed is identified to have more contribution towards obtaining the MRR, followed by the feed rate. The cutting speed contributes 49%, and the feed rate contributes 46.34%. The P value for both cutting speeds.
- In the case of multi-objective optimization carried out using GRA, the optimal settings optimized parameter for higher MRR and reduced SR is 900 rpm of cutting speed, 0.06 mm/rev of feed rate, and coated drill bit. The most significant factor is the drill bit, with 66.21% of the contribution. Similarly, the second most significant factor is cutting speed, with 20.09%. The least significant factor is feed rate, with an 8.91% contribution.

The spindle speed contributes 49%, and the feed rate contributes 46.34%. The p value for both spindle speeds.

• In the case of multi-objective optimization carried out using GRA, the optimal settings optimized parameter for higher MRR and reduced SR is 900 rpm of spindle speed, 0.06 mm/rev of feed rate, and coated drill bit. The most significant factor is the drill bit, with 66.21% of the contribution. Similarly, the second most significant factor is spindle speed, with 20.09%. The least significant factor is feed rate, with an 8.91% contribution.

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