Optimization of Process Parameters of AISI D3 Steel with Abrasive Assisted Drilling

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Abstract – ***This paper presents the optimization of process parameters for the surface finish & material removal rate during the drilling of AISI D3 steel with HSS drill. This study includes drilling of AISI D3 steel with supply of silicon carbide abrasive having grain size 1200µm mesh size through abrasive slurry & with coolant also. The slurry concentration has been varied from 15-35% by weight. Abrasive slurry performs the function of coolant as well as increases the surface finish, MRR. Experiments were conducted on a CNC machine. Taguchi was applied for executing the planning of experiments. The drilling parameters including spindle speed (RPM), feed rate (mm/min), and slurry concentration are optimized using multiple performance characteristics for surface roughness and MRR. Although, feed rate and spindle speed, slurry concentration were the most significant factors which affect the surface roughness but an overall improvement of 26.51% in the surface roughness has been witnessed with the aid of abrasive slurry. The feed rate was the most significant factor for the material removal rate during the abrasive assisted drilling.***

Key Words: *Drilling, MRR, surface roughness, Taguchi method, Abrasive, Twist drill.*

1. INTRODUCTION

Drilling is a process of producing round hole in solid material or enlarging existing hole with the use of multi-point cutting tools called drill or drill bits. Various cutting tools are available for drilling, but the most common is the twist drill. Drilling is one of the most fundamental machining processes. It is most frequently performed in material removal and it is used as a preliminary step for many operations such as reaming, tapping and boring. It is moving toward high speed applications for productivity enhancement. It has found that high production machining and drilling with high cutting velocity, feed and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature which reduces surface finish and tool life. Twist drills are the most common cutting tools used with drilling machines.
They are called twist drills mainly because of the helical flutes or grooves that wind around the body from the point to the neck of the drill and appear to be twisted. Twist drills are simply constructed but designed very tough to withstand the high torque of turning, the downward pressure on the drill, and the high heat generated by friction.

2 LITERATURE REVIEW

A comprehensive review of literature on diverse aspects of grinding and machining of AISI D3 steel has been presented here. M. Ramulu [20] conducted studied on Al2O3 based metal matrix composites by using different drills. It was found that PCD drills outperformed all other drills in terms of drilled-hole quality and minimum drilling forces induced. As per T. Rajmohan [26] drilling parameters namely spindle speed, feed rate, drill type and mass fraction of mica were optimized. The feed rate and the type of drill are the most significant factors which affect the drilling process and the performance in the drilling process. Erkki Jantunen [10] examined the monitoring methods, signal analysis and diagnostic techniques for tool wear and failure monitoring in drilling. Gul Tosun [12] analyzed the surface integrity of drilled Al/17%SiC particulate MMCs. Dry drilling tests, at different spindle-speed, feed rates, drills, point angles of drill and heat treatment, were conducted in order to investigate the effect of the various cutting parameters on the surface quality and the extent of the deformation of drilled surface due to drilling. In the experimental results, it is determined that increasing drill hardness and feed rate decrease the surface roughness of drilled surface for all heat treated conditions. H.S. Liu [14] investigated that in-process prediction of corner wear in drilling operations on synthesis of polynomial networks (ASPNs). It has been shown that the thrust force is better than the torque as the sensing signal for the in-process prediction of corner wear. Experimental results have shown that the corner wear over a wide range of drilling conditions can be predicted with a reasonable accuracy if the cutting speed, feed rate, drill diameter, and thrust force are given. Scott F. Miller [25] studied on the tool wear in friction drilling, a nontraditional hole-making process. Results indicate that the carbide tool is durable, showing minimal tool wear after drilling 11,000 holes, but observations also indicate the progressively severe abrasive grooving on the tool tip. C.C. Tsao [7] optimized the all machining operations; drilling using twist drill is the most frequently applied for secondary machining of composite materials owing to the need for structure joining. This study presents a comprehensive analysis of De-lamination caused by the drill wear for twist drill in drilling carbon fiber-reinforced composite materials. It results demonstrate that though the critical thrust force is higher with increasing wear ratio, the De-lamination becomes more liable to occur because the actual thrust force increases to larger extent. Quan Yanming [22] analyzed the tool wear in the cutting of SiC particle-reinforced aluminum matrix composites with special attention paid to the effects of material structures on the tool wear mechanism. The results of experiments show that the cutting of composites reinforced by coarse SiC particles requires tools which have high hardness: conventional tools are only adaptable to cut composites reinforced by fine SiC particles. J.Pradeep Kumar [16] utilized Taguchi method to investigate the effects of drilling parameters such as cutting speed , feed rate and drill tool diameter on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill. Yogendra Tyagi [28] investigated the drilling of mild steel with the help of CNC drilling machine operation with the use high speed steel by applying Taguchi methodology. Different machining parameters i.e. spindle speed, depth of cut and feed rate were investigated in order to minimize the surface roughness and to maximize the material removal rate. B. Ramesh [4] analyzed a non laminated Glass Fiber Reinforced Plastic (GFRP) composite manufactured by pultrusion process. Drilling was done with a coated cemented carbide drill. Feed significantly influences both the thrust force and torque with 88.52% and 92.83% respectively whereas the influence of spindle speed on the above was relatively insignificant. Kapil Kumar [18] investigated the optimization of cutting parameters for improving surface finish of stainless steel SS304 in the abrasive assisted drilling. Feed rate and spindle speed are the most significant factors which affect the surface roughness but an overall improvement of approximately 11% in the surface roughness has been witnessed with the aid of abrasive slurry. Arshad Noor Siddiquee [3] focused on optimizing deep drilling parameters based on Taguchi method for minimizing surface roughness. All four cutting parameters significantly affected the surface roughness with maximum contribution from speed (27.02%), followed by cutting fluid (25.10%), feed (22.99%), and hole-depth (14.29%). B.V.Kavad [5] studied that both vibration assisted drilling and Ultrasonic assisted drilling are more appropriate for drilling of GFRP. Gaurav Chaudhary [11] studied that Metal matrix composites (MMCs) consisting of two or more physically/chemically distinct phases are potential material for aerospace, automobile, defense, sport and research industries. Kamaldeep Singh [17] has done research work to find optimum process parameters for abrasive assisted surface grinding of AISI D3 tool steel. This study demonstrates that c-BN grinding wheel is preferred for higher MRR and Al2 O3 grinding wheel for better surface finish. Depth of cut is the most significant factor for both MRR and surface roughness.

3. EXPERIMENTATION

The HAAS TM1 Vertical Milling machine was used for experimentation. The twist drill bit was used in machining the work-piece. Preparing the slurry by taking concentration (gm/ml) of 15%, 25%, and 35%, with abrasive powder of Silicon carbide which has grit size 1200 µm. Stop-watch was used to determine material removal rate (MRR). For measuring surface roughness Mitutoyo (Surftest-4) was used. The corresponding MRR and surface finish was recorded for each experiment.

3.1 Machining Setup

The entire machining was carried out on 3-Axis HAAS TM1 Vertical Milling machine as shown in Figure 1. The HSS drill bit was used for drilling operation, diameter of 10 mm having two Flutes. Abrasive slurry of the silicon carbide (SiC) having grain size 1200 mesh was used as cutting fluid for present work. The slurry was used with varying concentration of 15%, 25%, and 35%. The work material used for the experimentation is AISI D3 steel. It is a high carbon high chromium tool steel. Material was cut into rectangular flats of 305*66*12 mm.

Fig -1: Machining Setup

3.2 Control factors and their limits

Table -1: Different control variables & their level

Factors	Levels	Level 1	Level 2	Level 3
Speed of Spindle (RPM) (A)	3	400	500	600
Feed Rate (mm/min) (B)	3	30	50	80
Slurry concentration (%) (C)	3	15%	25%	35%

3.3 L9 orthogonal array

In the present investigation, three different process parameters have been selected such as feed rate, spindle speed (RPM), and slurry concentration have three levels each. As per the requirements of the study, L9 orthogonal array has come out as one of the possible solutions for designing the experiments.

Table -2 L9 orthogonal array

Sr. No.	Spindle Speed(RPM)	Feed (mm/min)	Slurry Const. (%)
1	400	30	15
2	400	50	25
3	400	80	35
4	500	30	35
5	500	50	15
6	500	80	25
7	600	30	25
8	600	50	35
9	600	80	15

3.4 Experimental procedure

Firstly the material was cut into two equal parts of rectangular flats of size 305*66*12mm. After cutting, the AISI D3 steel material was holding on the vice fitted on CNC Machine. Then a program was made for each experiment as per the input parameters in orthogonal array. For each experiment, three holes were drilled into the AISI D3 steel plate to reduce error by taking the mean value. During the experiments, the abrasive slurry of Silicon carbide was used for first plate and coolant was used for second plate. Time taken for drilling operation on work piece was recorded with the help of stop watch. Then surface roughness of work piece was measured with the help of Mtiutoyo Surftest-4 for all the machined samples.

4. RESULTS & DISCUSSIONS

After conducting the experiments with abrasive slurry, the values of output variables (MRR & surface roughness) were recorded & plotted as per Taguchi's design & methodology. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. The detailed description of the analysis is given as under.

Table -3: Observation table

Exp. No.	MEAN MRR (mm^3/sec)	S/N Ratio(dB)	Mean Ra	S/N (d/B)
1	33.26	30.44	3.62	-11.17
2	48.75	33.76	4.17	-12.4
3	104.67	40.4	5.39	-14.64
4	37.72	31.53	4.41	-12.9
5	56.57	35.05	4.21	-12.48
6	91.35	39.21	4.97	-13.93
7	34.06	30.64	2.59	-8.27
8	60.18	35.59	4.95	-13.89
9	101.18	40.1	5.09	-14.14

4.1 Effect on MRR

It is observed that the feed rate affects the Material Removal rate significantly. As the feed rate increases there is increase in material removal rate. With the lower of feed rate, material removal rate is also low. The maximum material rate value is observed at the feed rate of 80 mm/min.

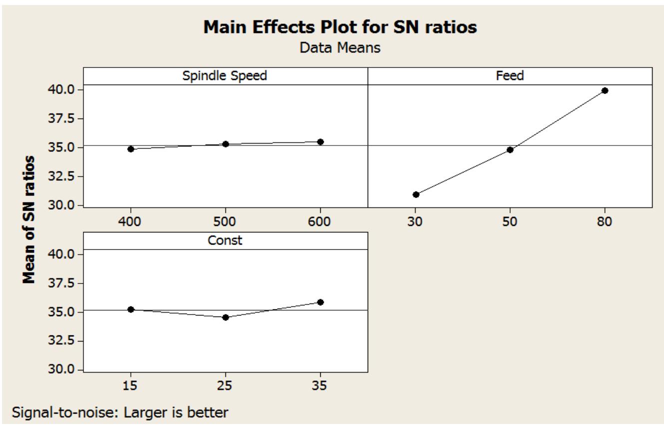

Chart -1: Plot for S/N ratio (MRR)

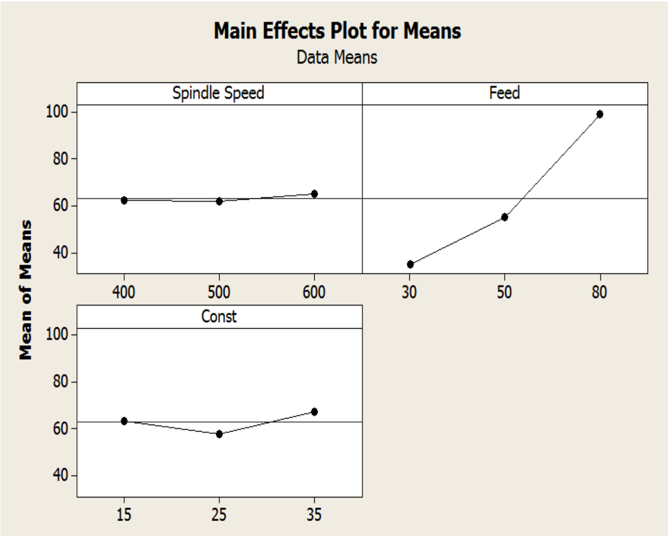

Chart -2: Plots for Mean (MRR)

It is observed that material removal rate is maximum at feed rate 80 mm/min, spindle speed of 600 rpm, and slurry concentration of 35%. Also material removal is minimum at feed rate of 30 mm/min, spindle speed of 400 rpm and slurry concentration of 25%.

4.2 Effect on Surface Roughness

It is observed that the lower value of surface roughness is obtained with the abrasive assisted drilling as compared to the drilling with coolant. This can be explained on the basis of low removal rate during the silicon abrasive assisted drilling. As the removal rate is low, very less cavities found on the surface during drilling.

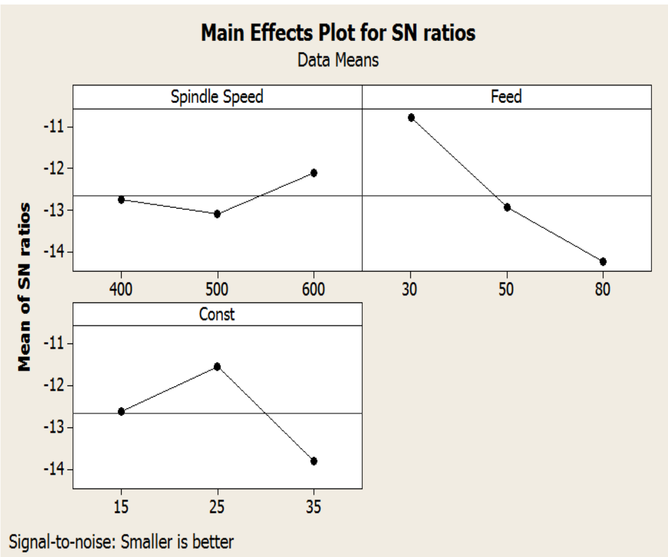

Chart -3: Plot for S/N ratio (Surface roughness)

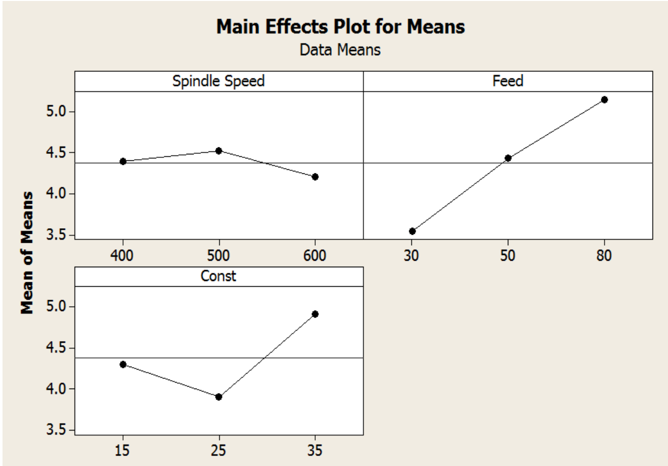

Chart -4: Plot for Mean (Surface roughness)

Feed rate affects the surface roughness the most. It is observed that Surface finish is maximum at feed rate of 30 mm/min, spindle speed of 600 rpm, and slurry concentration of 25%. Also Surface finish is minimum at feed rate of 80 mm/min, spindle speed of 500 rpm, and slurry concentration of 35%.

4.3 Comparison-abrasive & coolant assisted drilling

For comparing abrasive assisted drilling with coolant assisted drilling, nine experiments were performed with SiC abrasive & SE-363 as coolant.

Table-4 Percentage comparison for MRR

Sr. No.	Abrasive Assisted Drilling MRR (mm^3/sec)	Drilling With Coolant MRR (mm^3/sec)	Improvement (%)
1	33.26	31.76	4.5
2	48.75	46.35	4.92
3	104.67	83.26	20.45
4	37.72	32.12	14.84
5	56.57	53.36	5.67
6	91.35	85.64	6.25
7	34.06	33.67	1.14
8	60.18	54.39	9.63
9	101.18	88.49	12.54
Average			8.88%

It observed that there is an average 8.88% increase in MRR when silicon carbide slurry is used instead of coolant.

Table-5 Percentage comparison for Surface Roughness

Sr. No.	Abrasive Assisted Drilling RA (μm)	Drilling With Coolant RA (μm)	Improvement (%)
1	3.62	4.84	25.16
2	4.17	5.63	25.89
3	5.39	6.97	22.68
4	4.41	5.04	12.38
5	4.21	5.71	26.29
6	4.97	7.12	30.24
7	2.59	5.11	49.28
8	4.95	5.97	17.14
9	5.09	7.23	29.61
Average			26.51%

It observed that there is an average 26.51% increase in Surface Roughness when silicon carbide slurry is used instead of coolant.

4.4 Analysis of Variance (ANOVA)

The percentage contribution of various process parameters on the selected performance characteristic can be estimated by performing analysis of variance test (ANOVA). Thus information about how significant the effect of each controlled parameter is on the quality characteristic of interest can be obtained. The total variation in the result is due to various controlled factors and their interactions and variation due to experimental error.

Table -6: ANOVA (MRR)

Source	DOF	SS	MS	F	P	Contribution (%)
A	2	0.530	0.265	3.860	0.206	0.419
B	2	123.076	61.537	896.530	0.001	97.465
C	2	2.534	1.266	18.460	0.051	2.006
Error	2	0.137	0.068			0.108
Total		126.277				

After investigating the above data it is found that feed rate with percentage contribution of 97.47% & slurry concentration (2.01%) are the significant factor for material removal rate. Spindle speed (0.42%) is non-significant parameters.

Table -7: ANOVA (Surface Roughness)

Source	DOF	SS	MS	F	P	Contribution (%)
A	2	1.548	0.773	0.470	0.680	5.013
B	2	18.265	9.132	5.540	0.153	59.155
C	2	7.769	3.884	2.360	0.298	25.161
Error	2	3.295	1.647			10.671
Total		30.876				

As per this experiment data for surface roughness, feed rate is the important factor to consider for surface finish during the abrasive assisted drilling of AISI D3 steel with a percentage of 59.16% and slurry concentration is also a important factor with contribution of 25.16%. Beside this, spindle speed has 5.01% contribution.

5. CONCLUSIONS

1. In case of surface finish, 25% slurry concentration and a feed rate of 30 mm/min with spindle speed of 600 rpm found to be optimized parameters for abrasive assisted drilling.
2. In case of Material Removal Rate, 35% slurry concentration and a feed rate of 80 mm/min with 600 rpm rotational speed found to be optimized parameters for abrasive assisted drilling.
3. When we compare the surface finish and MRR, the abrasive assisted drilling gives better result as compared to drilling with coolant.
4. In case of Abrasive assisted drilling (silicon slurry) versus drilling with coolant, the average improvement in surface roughness is 26.51%.
5. In case of Abrasive assisted drilling (silicon slurry) versus drilling with coolant, the average improvement in material removal rate is 8.88%.
6. All the selected parameters are affecting the results but feed rate has maximum effect on the surface finish in abrasive assisted drilling of AISI D3 steel.
7. Minimum value of Surface roughness is obtained at higher spindle speed (600 RPM) and lower feed rate (30 mm/min) at moderate slurry (25%) concentration.
8. The overall improvement in surface finish & MRR through use of abrasives in comparison to the plain coolant is very promising which will lead to huge savings in the cost and improvement in quality.

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