The Effect and Process Parameters During Conventional Drilling and Abrasive Water Jet Drilling

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ABSTRACT:
In Drilling is the important machining process in manufacturing industry. Optimization of process parameters during drilling operation has been key research in recent times. Overthe years, many methods were proposed for optimization of process parameters during drilling which are aimed to get good surface finish, good quality hole, good material removal rate etc. In this regard the present work focuses on comparative study on effect of process parameters during conventional drilling and Abrasive water jet drilling. In this particular work different process parameters such as Material, thickness, speed is taken. Experiments are conducted according to L9 Orthogonal array both on conventional and Abrasive water jet drilling. The final results of Material Removal Rate and Hole taper aresubjected to statistical analysis in Minitab19 software and Regression Analysis whose results are analyzed and compared to give conclusions.

Keywords: Taguchi Method, Material Removal Rate, Hole Taper, Minitab software.

I. Introduction

Drilling is the method of making holes in a work piece with metal cutting tools. Drilling is associated with machining operations such as trepanning, counter boring, reaming and boring. The rotating movement is common to all these processes combined with a linear feed. The drilling process can be simple in some aspects with turning and milling but the demands on chip breaking and the evacuation of chips is critical in drilling. Demanding it is to control the process and to remove the chips. Short holes occur frequently on many components and high material removal rate is a growing priority along with quality and reliability. Types of Drilling: Solid, trepanning, Counter boring, Reaming.

II. Approach to Product/Process Development

Classification Of Drilling Processes

Drilling processes can be divided into two groups

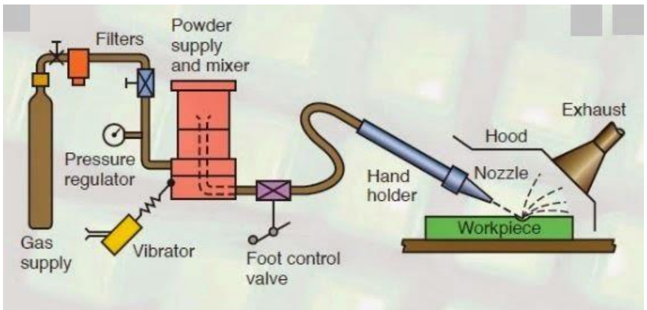
In **conventional** drilling process, there is direct contact between work piece and tool. The material is removed in the form of chips by applying forces on the work material with a wedge-shaped cutting tool that is harder than the work material.

In **unconventional** drilling, there is no direct contact between the tool and the work piece. In this process, a form of energy is used to remove unwanted material from a given work piece.

In unconventional drilling processes they classified into four types
1.Abrasive jet drilling,2. Abrasive water jet drilling,3. Water jet drilling,4. Ultrasonic drilling

Abrasive Water Jet Drilling

- In abrasive jet drilling, abrasive particles are made to impinge on the work material at a high velocity. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.
- The addition of an abrasive substance greatly increases the ability to cut through harder materials such as steel and titanium.
- The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.
- Water jet drilling can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problem such as cracked edge defects, crystallization, hardening are reduced in this process.



III. Steps Involved in Taguchi Method

The use of Taguchi's parameter design involves the following steps.

a. Identify the main function and its side effects.
b. Identify the noise factors, testing condition and quality characteristics.
c. Identify the objective function to be optimized.
d. Identify the control factors and their levels.
e. Select a suitable Orthogonal Array(OA) and construct the Matrix
f. Conduct the Matrix experiment.
g. Examine the data; predict the optimum control factor levels and its performance.
h. Conduct the verification experiment.

IV. Approach to the Experimental Design

Drilling is the very important machining process, without drilling we can't manufacture or construct anything, so drilling became unavoidable. Like any other machining process,drilling also can be done in conventional and non-conventional way. AWJ drilling is takenas non-conventional drilling. Always we can't use AWJ drilling since it is expensive and always, we can't use conventional drilling. Therefore, if we have a comparative study which can show at certain conditions which one is better. Then it will be helpful. So, three process parameters are taken and in each parameter three variations are taken. In L9 Orthogonal array 9 combinations of the process parameters are obtained and at each combination three holes are drilled both by AWJ and conventional drilling machines andthe results can be compared and analysed.

4.1 Parameter Design

It decides the optimum levels of control factors to maximize robustness and thereby enhances the performance. It involves the following steps

4.2 Selecting Process Parameters

- Three process parameters are selected. They are
  1. Thickness
  2. Material
  3. Speed
- In thickness, three levels are taken. They are
  1. 4mm
  2. 5mm
  3. 6mm
- In materials three types are taken. They are
  1. Aluminium
  2. Mild steel
  3. Composite material
- In speed also three levels are taken. They are
  1. 20% of the maximum speed
  2. 40% of the maximum speed
  3. 60% of the maximum speed

4.3 Preparation of composite material

-Composite material is prepared by HAND LAYOUT Method.
-Materials required: e-glass fiber mats (4) (each 1mm thick)
-Epoxy resin (LY556), Hardener (HY551), Weighing scale, Transparent film, Brushes
-Mansion polish, Rubber squeezes, Film cutter, Tape

Procedure

- Take 4 chopper glass mats each weighing 16grams approximately the total weight of the mats is 64 grams
- Take 128 grams of epoxy+hardener. For preparing these composites, the epoxy+hardener should be taken in 2:1 ratio with mats weight and for every 1Kgof epoxy, 10 grams of hardener is to be added.

The weight of mats = 64 grams
Weight of epoxy+hardener = 2*64 grams = 128 grams for hardener should be taken in 1:10 ratio with epoxyHardener weight = 12.8 grams
Epoxy weight = 128-12.8 = 115.2 grams

- Apply mansion polish inside the mug with a cloth which ensures easy removal without sticking. Take epoxy+hardener after applying polish and mix evenly using a brush
- Place a transparent film on a flat surface, and fasten it using a cello tape

- Apply mansion polish
- Using a brush apply a layer of epoxy mixture on film as per the size of the mat
- Place first mat and apply a layer of epoxy mixture over the mat
- Repeat the above steps till all mats are stacked
- Now place another film on the last epoxy layer and fasten
- Use rubber squeezer to remove any air bubbles
- This should be allowed to cure for at least 12 hours at normal temperature andpressures
- Before during, the entire mats+epoxy mixture along with the films can be placedwithin dies to mould into different shapes.
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Composite material

4.4 Selection of orthogonal array for conducting experiments

Orthogonal arrays are special matrices that enable the manufacturer to choose theparameter values with minimum number of experiments. In the matrix experiment the columns of the orthogonal array represent factors to be studied and each row represents a unique combination of factor levels in individual experiments. If a matrix is orthogonal,it implies that for any pair of columns all combination of factor levels occur equal number of times i.e. all factors are represented equally in all experiments. The total degree of freedom is required for the selection of a suitable orthogonal array. The degree of freedom is defined as the number of permissible variations in a process parameter to obtain a specific mean. To select an orthogonal array for experimentation, the number ofrows in the array should at least be equal to the total degrees of freedom of all factors andthe overall mean combined. Once the orthogonal array has been selected, experiments areperformed accordingly; and SNR for each experiment is calculated and tabulated. For timebeing, in this study L9 Orthogonal array is selected for conducting the experiments.

Drilling holes

a) Since, L9 Orthogonal array is selected therefore 9 combinations of given processparameters are obtained.
b) First of all, on Abrasive water jet Machine, at each combination three holes aredrilled.
c) For each hole machining time is noted and for the three holes mean machiningtime is calculated.
d) Same procedure is followed on conventional drilling machine also.

Drilled Aluminium plates

Drilled Mild Steel plates

Drilled composite plates

4.5 Result and Discussion

Machining Time

Abrasive Water Jet Drilling

During abrasive water jet drilling, the machining time of each hole is noted as follows

Machining time during AWJ drilling

Combinations			Machining time (Sec)		
Thickness	**Material**	**Speed**	**t_1**	**t_2**	**t_3**
T1	M1	S1	3.9	4.1	4
T2	M1	S2	4.6	4.6	4.6
T3	M1	S3	4.9	5	5.1

For each combination, mean time is calculated as follows

$T_{mean}(sec) = t_1+t_2+t_3 / 3$

$= 3.9+4.1+4 / 3$

$= 4$ sec

Similarly, for all combinations, mean time is calculated and tabulated as follows

Mean machining time during AWJ drilling

Combinations			Mean time
Thickness	**Material**	**Speed**	**Tmean (sec)**
T1	M1	S1	4
T2	M1	S2	4.6
T3	M1	S3	5
T1	M2	S2	6.4
T2	M2	S3	7.8
T3	M2	S1	8.3
T1	M3	S3	3.2

T2	M3	S1	3.4
T3	M3	S2	3.3

Conventional Drilling

At each combination, three holes are drilled. For each hole, the micrometer is kept at twoperpendicular positions and diameters are noted. Upper diameter for each hole is calculated by taking the mean of those two diameters. Similarly, lower diameter for each hole also calculated and tabulated as follows.

Diameters of each hole during Conventional drilling

Combinations			**Upper diameter**			**Lower diameter**		
Thickness	**Material**	**Speed**	**d_1**	**d_2**	**d_3**	**d1**	**d_2**	**d_3**
T1	M1	S1	5.1	5.08	5.095	4.915	4.96	5.01
T2	M1	S2	4.985	4.99	4.965	4.895	4.895	4.84
T3	M1	S3	5.015	5.005	5.105	4.895	4.92	4.9

Using above table, for each combination of process parameters mean upper diameterand mean lower diameter is calculated as follows

Mean upper diameter (D_1) = $d_1+d_2+d_3$ /3

= 5.1+5.08+5.095

= 5.0916 mm

Mean lower diameter (D_2) = $d_1+d_2+d_3$ /3

= 4.915+4.96+5.01 / 3

= 4.9616 mm

Similar process is followed in conventional drilling and mean upper diameter and meanlower diameter are calculated and tabulated as follows

Mean diameters of each hole during Conventional drilling

Thickness	**Material**	**Speed**	**Mean upper diameter (D1)(mm)**	**Mean lower diameter (D2)(mm)**
T1	M1	S1	5.0916	4.9616
T2	M1	S2	4.98	4.876
T3	M1	S3	5.0416	4.905

Using above table for each combination, hole taper is calculated as follows

Hole taper (θ) = $\tan^{-1}$(thickness/((D_1-D2)/2))

$90-\theta = \tan^{-1}(3/0.065)$

$\therefore \theta = 90-88.758$

$\therefore \theta = 1.242^\circ$

Similarly for each combination, hole taper is calculated and tabulated as follows

Hole taper during Conventional drilling

Thickness	Material	Speed	Hole taper (°)
T1	M1	S1	1.242
T2	M1	S2	0.745
T3	M1	S3	0.783

4.6 Comparative Study

Material Removal Rate (MRR)

1. For Aluminium, % of MRR of abrasive water jet drilling greater than that of conventional drilling is
   Mean MRR for AWJ drilling = 17.1449 mm^3/sec
   Mean MRR for conventional drilling = 8.3356 mm^3/sec
   ∴ % of MRR increased = ((17.1449-8.3356)/1.71449)*100
   = 51.38 %
2. For Mild steel, % of MRR of AWJ drilling greater than conventional drilling is Mean MRR for AWJ drilling = 10.3670 mm^3/sec
   Mean MRR for conventional drilling = 6.0544 mm^3/sec
   ∴ % of MRR increased = 71.231 %
3. For Composite material, % of MRR of AWJ drilling greater than conventional drilling is
   Mean MRR for AWJ drilling = 23.7524 mm^3/sec Mean MRR for conventional drilling = 9.482 mm^3/sec
   ∴ % of MRR increased = 60.07 %

Hole Taper

1. For Aluminium, % of hole taper of conventional drilling less than that of AWJdrilling is
   Mean hole taper for AWJ drilling = 1.8276˚
   Mean hole taper for conventional drilling = 0.923˚
   ∴ % of hole taper reduced = ((1.8276-0.923)/1.8276)*100
   = 49.49 %
2. For Mild steel, % of hole taper of conventional drilling less than that of AWJdrilling is
   Mean hole taper for AWJ drilling = 1.5991˚
   Mean hole taper for conventional drilling = 0.5949˚
   ∴ % of hole taper reduced = 62.79 %
3. For Composite material, % of hole taper of conventional drilling less than that ofAWJ drilling is
   Mean hole taper for AWJ drilling = 0.8759˚
   Mean hole taper for conventional drilling = 0.474˚
   ∴ % of hole taper reduced = 45.78 %

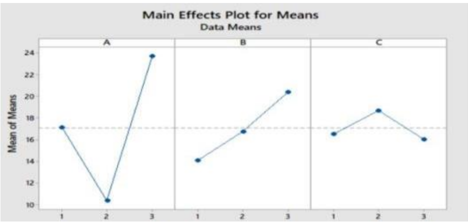
4.7 Graphs VIA Minitab19 software:

A statistics package developed by some researchers to help six sigma professionals analyze and interpret data to help in the business process is called Minitab.

The data input is simplified so that it can be easily used for statistical analysis and it also helps in manipulating the data set. If trends, patterns and charts are given, those are analyzed and interpreted so that final conclusions can be made. The answers are given and those are magnified with the givenproducts or services to help in the business. Problem solving is made easy and faster withthe Minitab tool. By taking the obtained results as input some statistical analysis is doneboth for AWJ drilling and conventional drilling and both are compared as follows.

4.8 Material Removal Rate

Abrasive water jet drilling **Conventional drilling**



Comparison of mean of means graph for MRR

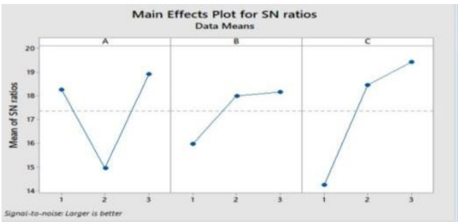
Response Table for Means

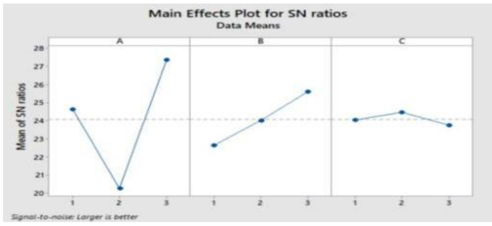
Level	A	B	C
1	8.336	6.564	5.222
2	6.054	8.200	9.293
3	9.483	9.109	9.358
Delta	3.428	2.545	4.136
Rank	2	3	1

Response Table for Means

Level	A	B	C
1	17.14	14.11	16.55
2	10.37	16.75	18.68
3	23.75	20.40	16.04
Delta	13.39	6.29	2.64
Rank	1	2	3

Comparison of Means Response tables for MRR





Comparison of SN ratios graph for MRR

Response Table for Signal to Noise Ratios
Larger is better

Level	A	B	C
1	24.62	22.65	24.03
2	20.27	23.99	24.47
3	27.35	25.60	23.74
Delta	7.08	2.95	0.73
Rank	1	2	3

Response Table for Signal to Noise Ratios
Larger is better

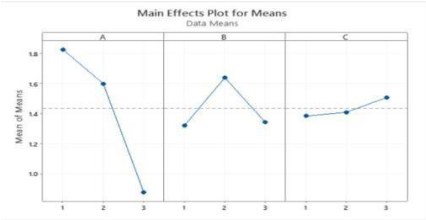
Level	A	B	C
1	18.26	15.97	14.23
2	14.93	17.98	18.45
3	18.91	18.15	19.42
Delta	3.97	2.19	5.19

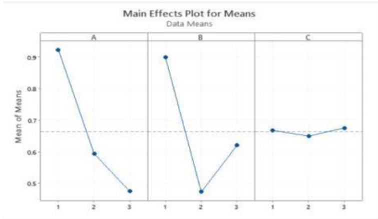
Comparison of Means Response tables for MRR

Hole Taper

Abrasive water jet drilling **Conventional drilling**

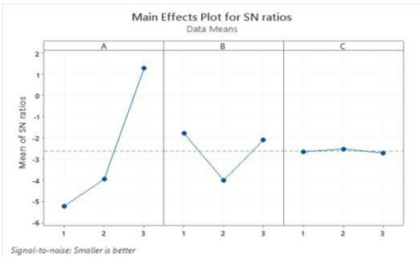
1) Mean of means graph

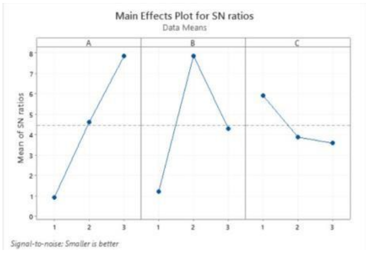




Comparison of mean of means graph for Hole taper

2) Mean of SN ratios graph





Comparison of SN ratios graph for Hole taper

3) Response tables

Response Table for Means

Level	A	B	C
1	1.8276	1.3207	1.3844
2	1.5991	1.6396	1.4096
3	0.8759	1.3423	1.5087
Delta	0.9517	0.3189	0.1243
Rank	1	2	3

Response Table for Means

Level	A	B	C
1	0.9233	0.8992	0.6679
2	0.5949	0.4730	0.6497
3	0.4749	0.6209	0.6756
Delta	0.4484	0.4262	0.0259
Rank	1	2	3

Comparison of Means Response tables for Hole taper

Response Table for Signal to Noise Ratios
Larger is better

Level	A	B	C
1	5.233	1.779	2.659
2	3.958	4.007	2.522
3	-1.296	2.109	2.714
Delta	6.530	2.228	0.193
Rank	1	2	3

Response Table for Signal to Noise Ratios
Larger is better

Level	A	B	C
1	-0.9331	-1.2143	-5.9156
2	-4.6035	-7.8676	-3.8805
3	-7.8416	-4.2962	-3.5822
Delta	6.9085	6.6533	2.3334
Rank	1	2	3

Comparison of SN ratios Response tables for Hole taper

V. Conclusion

Material Removal Rate (MRR)

1. It is known that MRR is inversely proportional to time. But, during AWJ drilling even though the machining time increases, MRR is increasing. Since, thicknessis increasing which results in the increase in the volume of the material removed.
2. The MRR is comparatively higher in AWJ drilling than in conventional drilling for the same values taken which justifies the higher productivity of AWJ drilling.
3. So, for the given application of drilling a hole where productivity is the criteria then AWJ drilling is chosen rather than conventional drilling.
4. The MRR is noted to be highest for composite material followed by aluminium and MRR is lowest for steel which can be attributed to higher hardness of the material.
5. So, the suitability of AWJ drilling is higher for the composite materials comparedto aluminium and steel.
6. The MRR is seen to be steadily increased with the increase in cutting speed.
7. For Aluminium, % of MRR of AWJ drilling greater than that of conventionaldrilling = 51.38%
8. For Mild steel, % of MRR of AWJ drilling greater than that of conventionaldrilling = 71.231%
9. For Composite material, % of MRR of AWJ drilling greater than that ofconventional drilling = 60.07%

Comparison of MRR between AWJ drilling and Conventional drilling

Combinations			**in AWJ drilling(mm^3/sec)**	**RR in Conventional drilling (mm^3/sec)**
T1	M1	S1	14.7261	6.1939
T2	M1	S2	17.0738	9.513
T3	M1	S3	19.6349	9.300
T1	M2	S2	9.20385	4.409
T2	M2	S3	10.0691	9.6842
T3	M2	S1	11.8282	4.0702
T1	M3	S3	18.4077	9.090
T2	M3	S1	23.0998	5.4016
T3	M3	S2	29.7498	13.957

Hole Taper

1. By comparing the values of hole taper, it is observed that lower taper is obtained during conventional drilling compared to AWJ drilling.
2. So, for the given application of drilling a hole where quality of hole is thecriteria, then it is better to choose conventional drilling rather than AWJ drilling
3. During AWJ drilling, it is observed that for same material, hole taper iscomparatively more at medium level of thickness.
4. During conventional drilling, it is observed that for same material, hole taper iscomparatively more at small thickness.

5. During conventional drilling, composite material gives less hole taper whencompared with other materials.
6. For Aluminium, % of hole taper of conventional drilling less than that of AWJdrilling = 49.49%
7. For Mild steel, % of hole taper of conventional drilling less than that of AWJdrilling = 62.79%
8. For Composite material, % of hole taper of conventional drilling less than that ofAWJ drilling = 45.78%

Comparison of Hole taper between AWJ drilling and conventional drilling

Combinations			**e taper in AWJdrilling (°)**	**Hole taper in conventional drilling(°)**
T1	M1	S1	1.747	1.242
T2	M1	S2	1.8687	0.745
T3	M1	S3	1.8672	0.783
T1	M2	S2	1.518	0.707
T2	M2	S3	1.9167	0.495
T3	M2	S1	1.3176	0.5827
T1	M3	S3	0.6971	0.7487
T2	M3	S1	1.0885	0.1791
T3	M3	S2	0.8422	0.497

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