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OPTIMIZATION OF PROCESS PARAMETERS OF ABRASIVE WATER JET MACHINING (AWJM) ON H13 HOT DIE TOOL STEEL AND D2 TOOL STEEL BY TAGUCHI METHOD

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ABSTRACT:
The hot work applications like extrusion tools, pressure die casting tools, forging dies and stamping dies requires high hardenability, excellent wear resistance, high toughness, thermal shock resistance and very high polish. H-13 hot die tool steel and D2 tool steel commonly used to satisfy these requirements. AWJM can be used for drilling, cutting, debarring, cleaning and etching. As a part of our work, AWJM of H-13 die tool steel and D2 tool steel is considered for the study. Because of its high hardness and strength H-13 hot die tool steel and D2 tool steel cannot be machined through traditional machining processes to achieve high surface finish and tight tolerances. Abrasive Water Jet Machining (AWJM) is employed because of its tight tolerances and high surface finish and faster cut. D2 is widely used in long production cold work applications requiring very high wear resistance and high compression strength. D2 steel is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties.
In this work transverse speed, standoff distance and abrasive flow rate are considered as parameters and their effect on performance measures. The main intent of this paper is to optimize the process parameters such as the pressure of water, flow rate of the abrasives used and the stand-off distance in H-13 hot die tool steel and D2 tool steel in order to obtain the minimized kerf taper angle and surface roughness. Parameters of abrasive water jet machining were optimized by employing Taguchi's technique.
Keywords: Abrasive water jet machining; H-13 hot die tool steel D2 tool steel Kerf taper angle; Optimization; Taguchi; Analysis of variance.

1.0 INTRODUCTION

Process optimization is the discipline of adjusting a process so as to optimize makes the best or most effective use of some specified set of parameters without violating some constraint. The most common goals are minimizing cost and maximizing through put and efficiency. Abrasive water jet machining is one of the primarily utilized non-traditional machining processes as it tends to cut highly hard and brittle materials and it is a best alternative for the traditional machining processes.

H13 Hot die Tool Steel:

H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications. Because of its excellent combination of high toughness and resistance to thermal fatigue cracking (also known as heat checking) H13 is used for more hot work tooling applications than any other tool steel.

Applications of H13 hot die tool steel:

Typical applications include die casting dies for H 13 die steel has various applications,

- Hot-work tool steel for universal use.
- Pressure casting dies and metal extrusion tools for processing light metals,
- forging dies,
- Screws and barrels for plastic processing, nitride ejectors, hot-shear blades.
- Hot-work tool steel for universal use

D2 Tool steel

Tool steel refers to a variety of carbon steel and alloy steel that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation, and their ability to hold a cutting edge at elevated temperatures. D2 steel is an air hardening, high-carbon, high-chromium tool steel.

Applications of D2 tool steel:

- Main applications are
- Stamping tools
- Punches and dies
- Forming dies

Water jet machine

Water jet cutting is a cold cutting process that eliminates slag deformation and dross waste unfortunate effects found in plasma and laser cutting processes. Additionally, both the garnet used in abrasive cutting as well as the water are recyclable. Water Jet Machining (WJM) also called water jet cutting is a non-traditional machining process in which high-velocity jet of water is used to remove materials from the surface of the work piece.

Fig1.1: Water jet machine

Limitations of Abrasive Water Jet Machining:

- Cannot drill flat bottom
- Cannot cut materials that degrades quickly with moisture
- High capital cost
- High noise levels during operation
- Surface finish degrades at higher cut speeds which are frequently used for rough cutting

Objectives of Abrasive Water Jet Machine:

- To achieve the shortest machining time whilst at the same time satisfying the requirements of accuracy and surface roughness.
- To discuss the cause – effect relationship of machining parameters & machine performance in abrasive water jet machine.
- To determine significant parameters affecting the machining performance.
- To establish the mathematical models relating the machining performance & machining parameters by response surface methodology.
- Finally, the optimal machining parameters are obtained under the constraints & requirements.

Scope of the Work:

The scope of the present work can be expressed in two ways. H13 hot die tool steel is used in many manufacturing companies and machining industries now-a-days to manufacture tools for different types of machining because it has very high strength for a material so hard and rigid. Its compressive strength is higher than virtually all melted, casted or forged metals and alloys. In this work, attempts have been made to investigate the machining characteristics of the H13 hot die tool steel during AWJM process. Therefore, the present work may give some guidelines for the researchers working on the AWJM of H13 hot die tool steels. In the second part of this work, optimal combination(s) of input parameters are obtained by employing various optimization techniques. This part provides guidelines to the engineers working in the field of AWJM to select the proper combination(s) of input parameters for the best process performance.

2.0 LITERATURE REVIEW

Thilak-et-al [1] have studied the effect of process parameters such as Water pressure, cutting speed, abrasive flow rate, and standoff distance on Top kerf width, bottom kerf width and kerf ratio. They used Grey relational analysis to optimize the performance measures on abrasive water jet machining of aluminium 6063.

FarhadKolahan et al [2] used abrasive water jet machining of 6063-T6 aluminium alloy to optimize input process parameters. They used Taguchi method and regression modelling to optimize nozzle diameter, jet traverse rate, jet pressure and abrasive flow rate for depth of cut.

Parthiban; [3] have done work on the machining of stainless steel AISI 316L by abrasive water jet machining. They considered Abrasive flow rate, cutting speed and stand of distance as input process parameters

K. S. Jai Aultrin et al [4] have studied the effect of input process parameters such as waterjet pressure, rate of abrasive flow, diameter of the orifice, diameter of the nozzle and stand of distance on material removal rate and surface roughness. They considered Aluminium, Copper and Lead alloys for machining by abrasive water jet machine.

Grellier, A.; Siaut ZoranJurkovic, [5] have investigated the effect of process parameters on machining of stainless steel and aluminium alloy by abrasive water jet machine. They used regression modelling technique to generate mathematical model in terms of considered process parameters such as water pressure, abrasive flow rate, traverse rate, stand-of distance, material thickness and type of material to predict surface roughness.

3.0 METHODOLOGY

Taguchi method are statistical methods, sometimes called robust design methods, developed by Genchi Taguchi to improve the quality of manufacturing goods, and more recently also applied to engineering, biotechnology,

marketing and advertising. The Taguchi method optimizes design parameters to minimize variation before optimizing design to hit mean target values for output parameters. The method uses special orthogonal arrays to study all the design factors with minimum of experiments. Taguchi method is the optimize input process parameters in the machining of D2 tool steel and H-13 die tool steel by using Abrasive water jet machining (AWJM). The selected responses are Kerf angle of D2 tool steel and H13 hot die tool steel the chosen process parameters are Stand-off distance, Traverse speed and Abrasive flow rate. Optimization of process parameters is the key step in the Taguchi method to achieve high quality without increasing cost.

Taguchi Method:

Taguchi design of experiment is a powerful analysis tool for modelling and analysing the influence of control factors on performance characteristics. The most important stage in this method lies in the selection of control factors. Based on the literature survey three parameters viz. stand-off distance, traverse speed and abrasive flow rate each at three levels are considered for the present study.

$S/N = \log_{10}(1/n)\sum_{i=1}^{n}\frac{1}{y_{ij}^2}$ ..... (1)

$S/N = -\log_{10}(1/n)\sum_{i=1}^{n} y_{ij}^2$ ..... (2)

Where n= number of replications and; y_{ij}= observed response value

Where i = 1, 2.....n; j = 1,2...k.

Optimizations of AWJM of H 13 hot die Tool Steel by Taguchi Technique.

The Taguchi method is very helpful to reduce the number of experiments by its robust design. This can be done by design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate influence of process parameters on output performance measures. Optimization of AWJM by using Taguchi technique consists of several steps. These are explained below

Table: 3.1 Machining parameters and their levels

S. No	Parameters	Symbol	Level 1	Level 2	Level 3
1	Stand-off distance(mm)	X_1	2	3	4
2	Traverse speed(mm/min)	X_2	100	125	150
3	Abrasive flow rate(g/min)	X_3	120	145	170

Selection of orthogonal array:

Based on number of input process parameters and their levels the orthogonal array should be selected. For our experimentation we considered three input process parameters with three levels of each parameter. Based on this, L_9 orthogonal array selected L_9 orthogonal array design of experiment.

Table: 3.2 L9 Orthogonal Array

Ex. No	X_1	X_2	X_3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.0 RESULTS AND DISCUSSIONS

Table: 4.1 The Experimental Results

	Input parameters			Kerf geometry		Output parameter
S.No	Stand-off distance (mm)	Traverse speed (mm/min)	Abrasive flow rate (g/min)	Kerp top width (w_t)	Kerf bottom width(w_b)	Kerf angle of H13(Θ)
1	2	100	120	1.2	0.1	0.85
2	2	125	145	1.5	0.4	0.1
3	2	150	170	2.0	0.3	0.95
4	3	100	145	1.7	0.8	1.1
5	3	125	170	1.5	0.5	0.25
6	3	150	120	1.3	0.6	0.8
7	4	100	170	1.8	0.2	1.1

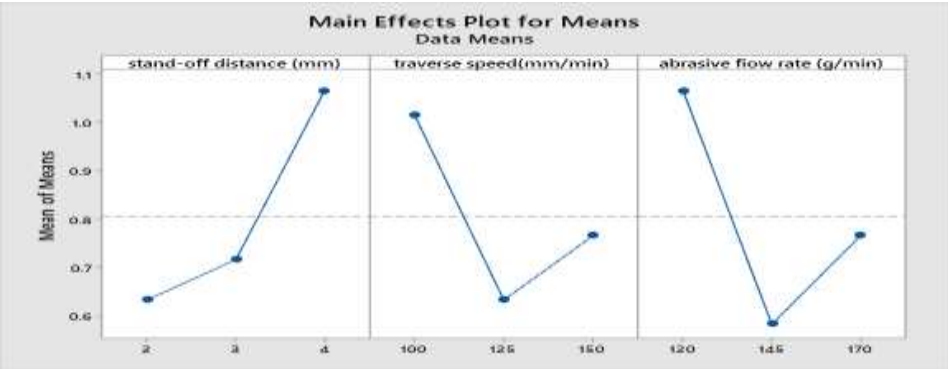
8	4	125	120	1.6	0.9	1.55
9	4	150	145	1.9	0.7	0.55

Table: 4.2 S/N ratios for Kerf angle of H13

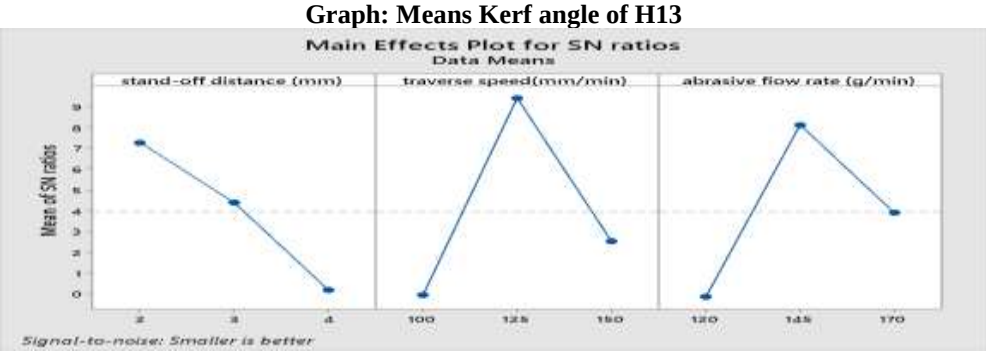
Level	Stand-off distance	Traverse Speed	Abrasive flow rate
1	7.28572	-0.08136	-0.15227
2	4.38385	9.41152	8.12163
3	0.18609	2.52549	3.88629
Delta	7.09963	9.49288	8.27390
Rank	3	1	2

Table 4.3: Means for Kerf of H13

Level	Stand-off distance	Traverse speed	Abrasive flow rate
1	0.6333	1.0167	1.0667
2	0.7167	0.6333	0.5833
3	1.0667	0.7667	0.7667
Delta	0.4333	0.3833	0.4833
Rank	2	3	1



Graph: Means Kerf angle of H13



Graph: Average S/N ratios of Kerf angle of H13 V/S Levels

Optimum Process Parameter Values of H13:

Table 4.4: Optimum process parameter values for kerf angle of H13

Parameters	Levels	Optimal values
Stand-off Distance(mm)	4	4
Traverse Speed(mm/min)	3	100
Abrasive flow rate(g/min)	2	120

The optimized value of Kerf angle (Θ) is 0.034

The Taguchi method is very helpful to reduce the number of experiments by its robust design. This can be done by design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate influence of process parameters on output performance measures.

Selection of process parameter of D2 tool steel:

In this work, machining of D2 tool steel can be done on AWJM. In this machining several factor scans influence the performance measures. But in which most significant parameters such as Stand-off distance, Traverse speed and Abrasive flow rate were chosen as input process parameters. Totally three control factors were chosen at three levels and we have studied their effect on performance measures such as kerf taper angle of D2 tool steel material.

The levels of parameters are shown in the table:

Table 4.5: Machining parameters and their levels

S. No	Parameters	Symbol	Level 1	Level 2	Level 3
1	Stand-off distance(mm)	X_1	2	3	4
2	Traverse speed(mm/min)	X_2	240	265	290
3	Abrasive flow rate(g/min)	X_3	250	275	300

Selection of Orthogonal Array:

Based on number of input process parameters and their levels the orthogonal array should be selected. For our experimentation we considered three input process parameters with three levels of each parameter. Based on this, L_9 orthogonal array selected L_9 orthogonal array design of experiment.

Table: 4.6 L9 Orthogonal Array

Ex. No	X_1	X_2	X_3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The Experimental values obtained are:

Table 4.7: The Experimental values

	Input parameters			Kerf geometry		Output parameters
S.No	Stand-off distance (mm)	Traverse speed (mm/min)	Abrasive flow rate (g/min)	Kerp top width (w_t)	Kerf bottom width(w_b)	Kerf angle of D2(Θ)
1	2	240	250	0.80	0.45	1.225
2	2	265	275	0.83	0.40	0.97
3	2	290	300	0.84	0.50	1.41
4	3	240	275	0.88	0.60	1.82
5	3	265	300	0.69	0.45	1.335
6	3	290	250	0.70	0.55	1.775
7	4	240	300	0.50	0.35	1.075
8	4	265	250	0.46	0.38	1.25
9	4	290	275	0.67	0.40	1.13

Generation of S/N ratio

S/N ratios for performance measure can be generated based on minimization of performance measure.

For the minimization for kerf angle of D2

S/N ratio for kerf angle of D2 = $-10log1/n(\Sigma^{n}{}_{j=0}\, y^{2}{}_{j})$

Within selected experimental domain the most significant factor becomes pressure of water abrasive flow rate and stand-off distance parameters in order to influence on responses.

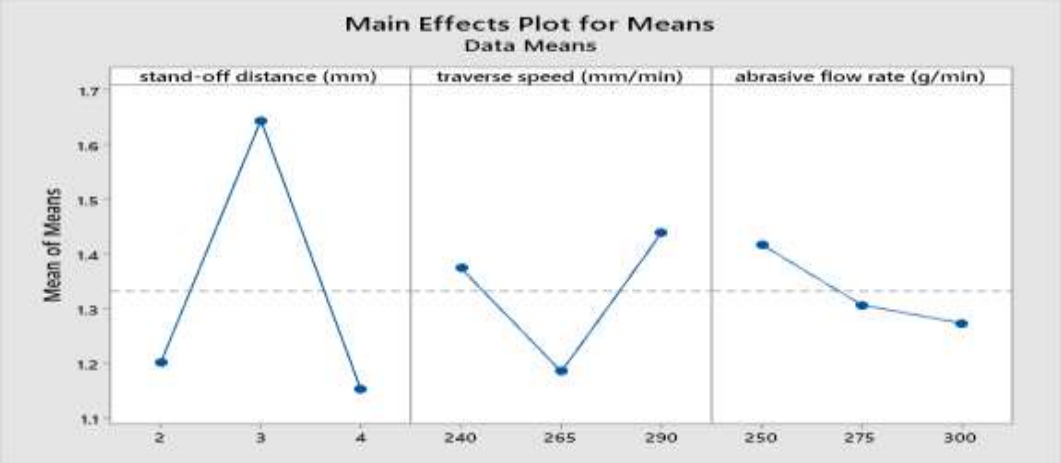
Table: 4.8 S/N Ratios Kerf Angle of D2

Level	stand-off distance	Traverse speed	Abrasive flow rate
1	-1.494	-2.531	-2.895
2	-4.232	-1.394	-1.999
3	-1.209	-3.010	-2.041
Delta	3.022	1.616	0.895
Rank	1	2	3

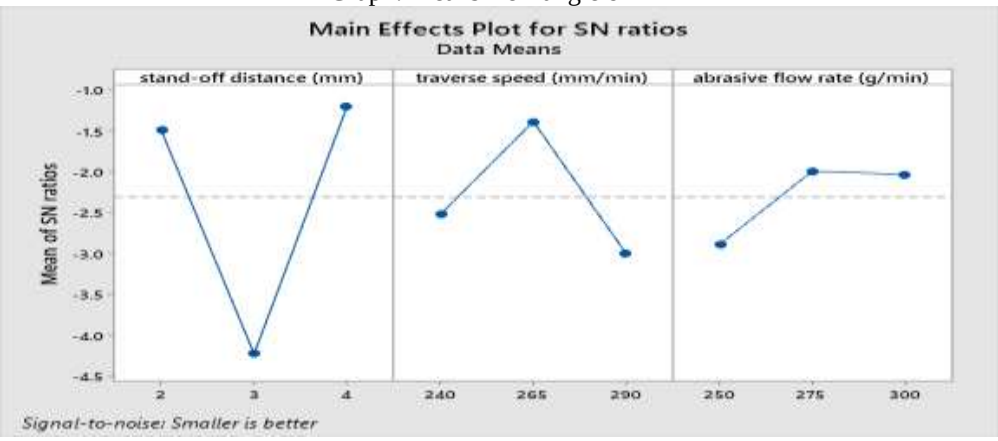
Table: 4.9 Means for Kerf Angle of D2

Level	stand-off distance	traverse speed	abrasive flow rate
1	1.202	1.373	1.417
2	1.643	1.185	1.307
3	1.152	1.438	1.273
Delta	0.492	0.253	0.143
Rank	1	2	3

Graphs related for kerf angle of D2



Graph: Means Kerf angle of D2



Graph: Average S/N ratios of Kerf angle of D2 V/S Levels

Optimum Process Parameter Values:

Table: 4.10 Optimum process parameter values for kerf angle of D2

Parameters	Levels	Optimal values
Stand-off Distance(mm)	4	3

Traverse Speed(mm/min)	3	240
Abrasive flow rate(g/min)	2	250

The optimized value of kerf angle (Θ) is 0.043

DICUSSIONS

Machining has been done on CNC abrasive water jet machine which employs S3015 model of water jet pump which has a maximum discharge and pressure of 1200 l/hr and 4000bars, respectively. The machine employs gravity feed type abrasive hopper, through which the abrasives are fed to the machining area. The assembly of the nozzle has an orifice diameter of 0.35mm. Aluminum oxide Garnet (80 mesh) has been used as an abrasive and a compressed air has been employed to fetch the abrasives to the machining area through abrasive feeder as well the mixing chamber. The trials for the machining have been done on H13 hot die tool steel and D2 tool steel by varying the input parameters such as pressure of the water, flow rate of the abrasives and the stand-off distance. The responses for find the kerf angle including the S/N ratio values.

CONCLUSIONS:

The response of the process parameters such as pressure of water, flow rate of the abrasives and SOD on the kerf taper angle of AWJM in H-13 hot die tool steel and D2 tool steel has been studied. The major outcomes of this research work have been listed below: Quality of cut surface in AWJM is dependent on so many process parameters. Process parameter which affects less or more on quality of cutting in AWJM are water pressure, size of abrasives, stand-off distance, abrasive floe rate, types of abrasives, orifice size, nozzle diameter and traverse speed. To be short, kerf taper angle increases, when the water pressure increases. When the flow rate of abrasives increases initially, a greater number of abrasives have been targeted towards the concentrated area, thereby more material gets removed.

Future scope:

Researchers have contributed in different directions but due to complex nature of the process a lot of works are still required to be done. The AWJM process is a suitable option in meeting the demands of today's modern applications.

- The AWJM of the modern composite, glass and advanced ceramic materials, which is showing a growing trend in many engineering applications, has also been experimented.
- It has replaced the conventional means of machining hard and difficult to cut material, namely the ultrasonic machining, laser beam machining and electro discharge machining, which are not only slow to machining but damage the surface integrity of the material.
- In addition, the AWJM process has sought benefits of combining with other material removal methods to further expand its applications and improve the machining characteristics. The optimization of process variables is a major area of research in AWJM.

Researchers have excluded many important factors such as nozzle size and orifice diameter during study which otherwise would affect the performance characteristics differently. Most of literature available in this area shows that researchers have concentrated on a single quality characteristic as objective during optimization of AWJM. Optimum value of process parameters for one quality characteristics may deteriorate other quality characteristics and hence the overall quality. So, more work is required to be done in this area.

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