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Research Article

Process Parameter Optimization of CNC Abrasive Water Jet Machine for Titanium Ti 6Al 4V

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Abstract

Abrasive water jet machining is one of the most non-conventional methods for machining. It is widely used in fabrication industry to machine the materials like aluminum, mild steel, copper, glass, titanium, hard rock material, graphite, ceramics, composite material, etc. Abrasive Water Jet Machining (AWJM) of Titanium (Ti 6Al 4V) has commercial importance due to its decent machining characteristics. In the present paper an effort has been made to optimize machining factors employed in Abrasive Jet Machining of Ti 6Al 4V using Taguchi technique. The methodology used is established on the analysis of variance and Grey Relation Analysis (GRA) to optimize the AWJM process factors for effective Material Removal Rate (MRR) and Surface Roughness (SR). Significant AWJM machining parameters such as traverse speed, abrasive flow rate & stand-off Distance were expected for optimized MRR and SR. It was set that determined optimal combination of AWJM process factors satisfy the actual need for Ti 6Al 4V in actual run-through.

Keywords: *Abrasive Water Jet Machine (AWJM), Grey Relation Analysis (GRA), ANOVA, MRR, SR*

1. Introduction

Among Titanium based alloys specifically Ti 6Al 4V has decent mechanical properties like great corrosion resistance the high strength, low weight ratio. It has good ability to resist oxidation. It is used in aircraft turbine engine components, aerospace, high-performance automotive parts, aircraft structural components, medical devices, marine applications, and sports kit. The alloy has great strength it cannot be machined by using the traditional methods as of its work hardening nature. Hence non-traditional techniques like laser machining and abrasive water jet machining etc. are used. Laser Cutting is normally economical for cutting Ti 6Al 4V sheets up to 2mm thick and beyond 2mm thick abrasive water jet machining is frequently used. On the other hand, AJWM is favored over laser cutting because of its capability to machine the components with minimum slot width. Abrasive water jet machining of grey cast iron, aluminum, mild steel and hard polymers and composites has been studied comprehensively for optimized material removal rate (MRR) and surface roughness (SR) using GRA method. Nozzle traverse speed and water pressure are major manipulating factors in case of MRR while abrasive mass flow rate and pressure intensely influences SR. Other factors such as standoff distance, abrasive grain size are sub-significant in influencing MRR or SR. It was illustrious that ferrous materials need expressively high abrasive flow rate compared to non-ferrous materials whereas composites and tough polymers can be machined through moderate abrasive flow rates. Abrasive jet water machining of Ti 6Al 4V was prevailing optimization of machining parameters did not receive much consideration. Hence in the existing work an effort has been made to optimize the cutting parameters in the AWJM of Ti 6Al 4V alloy using GRA method. Nozzle transverse speed, abrasive flow rate and standoff distance were optimized for surface roughness (SR) and material removable rate (MRR).Analysis of variance (ANOVA) and Gray relation analysis were used for optimization of machining parameters

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2. Experimental Details

2.1 Work piece material

Here work piece Titanium Ti 6Al 4V is having hardness of 33 HRC for the experiment. The Length and breadth of work piece was 120 mm and thickness of plate 16 mm. Ti 6Al 4V is a high strength alloy, which is used in a diversity of mechanical applications. Mechanical properties of this material are elastic modulus 120-130Gpa, density $4.42*10^3$ g/mm^3, tensile strength 860 MPa, yield strength 758 MPa.

2.2 Abrasive Material

Aluminum oxide consists of blunt shaped grains and is very hard in its lowest polished form. It is manufactured in variety of refinements and by its flexibility can be used to very hard to soft use, making it the very frequently used abrasive. The abrasive water jet machining apparatus used consists of a high pressure pump SL-V 50 Plus made by KMT that is built on a CNC AWJM cutting portal with an abrasive feeding arrangement that varies the feed rate in the range of 100 – 900 grams /min. 80Mesh Garnet sand was castoff as Abrasive material, the values of abrasive particles granulation varies in the middle of 160 - 310μm with a density of 2300 kg/m^3.

2.3 Nozzle

Cutting head consists of orifice, mixing chamber and focusing tube (Nozzle) or insert where water jet is formed and mixed with abrasive particles to form abrasive water jet. The orifice used had an inner diameter of 0.25 mm and the nozzle inner diameter was 0.75mm. Water passed through the pipes is carried to the jet or cutting head. The standoff distance between the mixing tube and the material is typically 0.5 mm to2.5 mm. more standoff (greater than 3 mm) can cause a frosting to appear at top of the cut edge of the material. Various Water jet systems reduce or reduce this frosting by cutting below water or using other methods.

2.4 Measurement of surface roughness and material removal rate

The surface roughness of the trials was measured with Mitutoyo make Surface roughness tester and the material removal rate measured by the calculation.

2.5 Design of experiment

In this study, four controllable variables, explicitly, traverse speed, Abrasive flow rate, and Standoff distance. In the machining factor design, three levels of the cutting parameters were carefully chosen, shown in Table 1. By table 1, L9 orthogonal array of Taguchi method has been carefully chosen for the experiments in MINITAB 15. 9 experiments will carried out with abrasives. SR and MRR have been selected as response variables. All these data are used for the study and evaluation of the optimal parameters combination. Experiment result as shown in Table2.

Table 1 Process parameters with their levels

Sr.No.	Process Parameter	Unit	Level-1	Level-2	Level-3
1	Traverse Speed(T)	Mm/min	30	55	80
2	Abrasive flow rate(F)	grams/min	200	250	300
3	Stand of distance(S)	mm	1	1.5	2

Table 2. Experiment Result

Ex.no	T	F	S	MRR (gm/min)	Ra (μm)
1	30	200	1	1.611	3.2632
2	30	250	1.5	1.758	2.9456
3	30	300	2	1.827	2.4786
4	55	200	1.5	2.601	4.0023
5	55	250	2	2.862	4.1896
6	55	300	1	2.781	3.1270
7	80	200	2	3.666	3.6713
8	80	250	1	3.735	3.3293
9	80	300	1.5	3.843	4.1636

3. Methodology

3.1 Grey relational analysis method

In Grey relational analysis, trial results were first normalized and then the grey relational coefficient (GRC) was calculated from the normalized experimental data to definite the relationship between the desired and actual experimental records. Then, the grey relational grade (GRG) was calculated by averaging the grey relational coefficient corresponding to every process response. The overall assessment of the multiple process responses is grounded on the grey relational grade (GRG).

3.2 Data preprocessing

In S/N ratio method this formula was used for MRR and SR

$$L_{HB} = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_{MRR}^2} \quad (1)$$

$$L_{LB} = \frac{1}{n}\sum_{i=1}^{n} y_{SR}^2 \quad (2)$$

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (3)$$

For Higher-the-Better (HB) criterion, the normalized data can be stated as:

$$x_i(k) = \frac{y_i - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (4)$$

Where x_i (k) is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k_{th} response, and max y_i (k) is the major value of y_i (k) for the k_{th} response.

An ideal sequence is x0(k) (k=1, 2) for dual responses. The definition of the grey relational grade in the grey relational

Analysis is to indicate the relational degree among the nine sequences $x_0(k)$ and $x_i(k)$, i=1, 2, . . . , 27; k=1, 2). The grey relational coefficient $\xi i(k)$ can be calculated as:

$$\xi_i(k) = \frac{\Delta_{min} + \theta\, \Delta_{max}}{\Delta_{0i}(k) + \theta\, \Delta_{max}} \quad (5)$$

Where Δi = | X0 (k) – Xi (k) | = difference of the exact value x0 (k) and xi (k); θ is the distinguishing coefficient 0 ≤ θ ≤ 1; minΔ = ∀j min ϵ i∀kmin= | X0 (k) – Xi (k) | = the lowest value of Δ0i; and maxΔ = ∀jmax ϵ i∀kmax = largest value of Δ0i. Later averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (6)$$

Where n = number of process responses. The higher value of grey relational grade corresponds to strong relational degree between the reference sequence x0 (k) and the set sequence xi (k). The reference sequence x0 (k) signifies the best process sequence. Therefore, higher grey relational grade means that the corresponding factor combination is nearer to the optimal.

4. Presentation and analysis of results

A level average analysis was accepted to deduce the results. This analysis is based on merging the data associated with each level for each parameter. The variance in the average results for the highest and lowest average response is the measure of the influence of that parameter. The highest value of this variance is related to the largest effects of that particular factor. Data pre-processing of each performance characteristic and the trial results for the grey relational conferring to formulas (1),(2),(3) and (4) are given in Table 3 and 4,5 and 6.

Table 3 Signal-to-Noise Ratio

Response Values		S/N Ratio	
MRR(gm/min)	Ra(μm)	MRR(dB)	Ra(dB)
1.611	3.2632	4.141911	-10.2729
1.758	2.9456	4.900377	-9.38348
1.827	2.4786	5.234771	-7.88413
2.601	4.0023	8.302807	-12.0462
2.862	4.1896	9.133393	-12.4435
2.781	3.1270	8.88402	-9.90256
3.666	3.6713	11.28385	-11.2964
3.735	3.3293	11.44581	-10.4471
3.843	4.1636	11.69341	-12.3894

Table 4 Normalize Value of SR, and MRR

Expt. No	Normalized S/N Ratio	
	MRR	Ra
1	0.0000	0.4761
2	0.1004	0.6711
3	0.1447	1.0000
4	0.5510	0.0871
5	0.6610	0.0000
6	0.6280	0.5573
7	0.9458	0.2516
8	0.9672	0.4379
9	1.0000	0.0119

Table 5 Deviation sequence and grey relational coefficient

Expt. No	Deviation Sequence		Grey Relational Coefficient		Gray relation Grade
	MRR	Ra	MRR	Ra	
1	1.0000	0.5239	0.3333	0.4883	0.4108238
2	0.8996	0.3289	0.3573	0.6032	0.4802464
3	0.8553	0.0000	0.3689	1.0000	0.6844529
4	0.4490	0.9129	0.5269	0.3539	0.4403807
5	0.3390	1.0000	0.5959	0.3333	0.4646376
6	0.3720	0.4427	0.5734	0.5304	0.5518801
7	0.0542	0.7484	0.9021	0.4005	0.651325
8	0.0328	0.5621	0.9385	0.4708	0.704605
9	0.0000	0.9881	1.0000	0.3360	0.6679945

In grey relational analysis greater the grey relational grade of experiment states that the corresponding experimental combination is optimum situation for multi objective optimization and gives enhanced product quality. Form the basis of the GRG, the factor influence can be estimated and the optimal level for each governable factor can also be determined. From the Table 5 It is found that experiment 8 has the best multiple performance characteristic among 9 experiments, because it has the highest grey relational grade of 0.7046.

Table.6: The Main Effects of the Factors on the Grey Relational Grade

Sym bols	Para meters	Grey Relational Grade			Main effect	Rank
		L-1	L-2	L-3		
A	T	0.5252	0.4856	**0.6746**	0.1890	1
B	F	0.5008	0.5498	**0.6347**	0.1339	3
C	S	0.5557	0.5295	**0.6001**	0.0705	2

From the table no. 6 it is conclude that the optimum condition for surface roughness is meeting at Traverse speed (A3), Abrasive flow rate (B3), Stand-off distance (C3).then by using this data the predicted MRR and SR were found out by Minitab software 4.0912gm/min and 2.3566 μm respectively.

Conclusion/Recommendations

The confirmation experiments were performed with the optimum combination of the machining parameters obtained from GRA Technique. The mentioned parametric combination for optimum material removal rate is T3F3S3 and after confirmation test the optimum response value of MRR is 3.9853 grams/min. The confirmation experiments were performed on Surface roughness with T3F3S3 levels as obtained from GRA Technique. The optimal response value for Surface roughness after confirmation test is 2.4658µm. These test results offers us a greater feature in decide on significant parameters on output parameters such as MRR, SR while machining Titanium Ti 6Al 4V material on abrasive water jet machining.

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