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Optimization of Parameters on Abrasive Water Jet Machining of Glass-Epoxy Laminate

G. J. Sushma Preetham[1], M. Sreenivasa Rao[2]
[1]*M. Tech. Student, Department of Mechanical Engineering, JNTUH, Hyderabad, India*
[2]*Professor, Department of Mechanical Engineering, JNTUH, Hyderabad, India*

***Abstract*: In the recent years, composites have taken prominence because they can be made strong and light, strong in a specific direction whereas metals are strong and heavy, equally strong in all directions. Abrasive Water Jet Machining (AWJM) is a non-conventional machining process that can machine hard materials and intricate shapes with no heat generation. In this study, Glass-Epoxy laminate is chosen as the material to be machined. Process parameters are varied during machining and performance measures are measured. Process parameters considered are water pressure, traverse rate and abrasive mass flow rate, Performance measures evaluated are material removal rate (MRR), surface roughness (Ra) and kerf. Selected process parameters are optimized using grey taguchi method for maximum material removal rate, minimum surface roughness and minimum kerf. Optimum values of the process parameters are found out by grey relational analysis. To study the influence of each process parameter on material removal rate, surface roughness and kerf, ANOVA is carried out. It is observed that water pressure and abrasive mass flow have strong influence on MRR and kerf and water pressure and traverse rate has more influence on surface roughness.**

***Keywords*: Abrasive water jet machining (AWJM), Glass-Epoxy laminate, Grey relational analysis, Material removal rate, Surface roughness and Kerf, Analysis of variance (ANOVA).**

1. Introduction

Glass Epoxy laminate is taken because of high dielectric strength, high tensile strength, low moisture absorption, high impact strength, radiation resistant, chemically resistant, low dissipation factor, cryogenic serviceability. The basic machining principle of abrasive water jet machine is removal of material by impact erosion. In this process, a focused stream of abrasive particles which is carried by high pressure water is made to impinge on the work surface through a nozzle and work material is removed by erosion by high-velocity abrasive particles. The various process parameters in AWJM are water pressure, traverse rate, abrasive mass flow rate, stand-off distance and type of abrasive particle.

2. Objectives and experimental work

A. Objectives

The important objectives of this dissertation work are the following.

- To study the effect of each process parameter of abrasive water jet machine on glass-epoxy laminate on the performance measures by experimental investigation.
- Optimization of the set parameters of the considered process would be carried out through Grey Taguchi Analysis.
- ANOVA analysis would be carried out to study the influence of each parameter on the selected performance measures.

B. Experimental work

The process parameters considered for machining are water pressure, traverse rate and abrasive mass flow rate at three different levels as shown in Table 1.

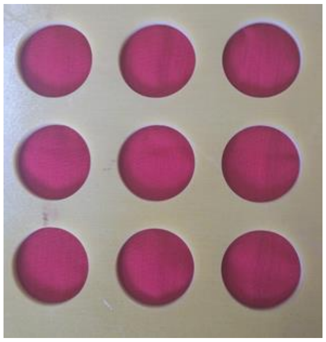

Fig. 1. Machined Glass-Epoxy laminate

Glass-Epoxy laminate of 5mm thickness is taken. Machining is done by accelerating garnet abrasives of mesh size 80 mixed with water at 600mm/min speed fast enough to cut through glass epoxy laminate exiting from the nozzle impacting on to

Table 1
Levels of process parameters

S. No.	Parameters	Level 1	Level 2	Level 3	Units
1	Water Pressure	280	300	320	MPa
2	Traverse Rate	600	800	1000	$^{mm}/_{min}$
3	Abrasive Mass Flow Rate	250	300	350	$^{gm}/_{min}$

Table 2
Experimental layout using an L9 orthogonal array and corresponding results

S. No.	Water Pressure (MPa)	Traverse Rate (mm/min)	Abrasive Mass Flow Rate (gm/min)	MRR (mm^3/min)	Surface Roughness R_a (μm)	Kerf
1	280	600	250	513	2.4	0.171
2	280	800	300	621	2.19	0.207
3	280	1000	350	363	2	0.121
4	300	600	300	714	2.37	0.238
5	300	800	350	618	2.2	0.206
6	300	1000	250	777	2.36	0.259
7	320	600	350	744	2.63	0.248
8	320	800	250	645	2.41	0.215
9	320	1000	300	879	2.8	0.293

Table 3
Optimization by grey taguchi method

	Normalized values			Grey relational coefficient $\xi_i(k)$			GRG ϒ
S. No.	MRR (mm^3/sec)	Surafce Roughness R_a (μm)	Kerf	MRR y_i (k)	R_a y_i (k)	Kerf y_i (k)	Grey relational grade
1	0.228984	0.500	0.709	0.395141	0.500	0.632	0.509
2	0.454831	0.763	0.500	0.48099	0.678	0.500	0.553
3	-0.08469	1.000	1.000	0.316647	1.000	1.000	0.772
4	0.64931	0.538	0.320	0.591685	0.519	0.424	0.512
5	0.448557	0.750	0.506	0.478104	0.667	0.503	0.549
6	0.781054	0.550	0.198	0.700967	0.526	0.384	0.537
7	0.712045	0.213	0.262	0.639134	0.388	0.404	0.477
8	0.505019	0.488	0.453	0.50539	0.494	0.478	0.492
9	0.994354	0.000	0.000	1	0.333	0.333	0.556

Table 4
Analysis of Variance for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Water Pressure	2	46.5966	59.89%	46.5966	23.2983	*
Traverse Rate	2	0.4582	0.59%	0.4582	0.2291	*
Abrasive Mass Flow Rate	2	17.0243	21.88%	17.0243	8.5121	*
Error	0	*	*	*	*	
Total	8	77.8077	100.00%			

the work piece. The abrasives are mixed in water jet is in such a way that water jet's momentum is transferred to the abrasives.

Experiment conducted based on L9 orthogonal array and the performance measures are material removal rate, surface roughness and kerf shown in Table 2.

3. Optimization and analysis of variance

Optimization is carried out by grey taguchi method on process parameters for maximum material removal rate, minimum surface roughness and minimum kerf. The steps of optimization is discussed below.

- Normalization is done with 'Higher the better'(HBT) for material removal rate and 'Lower the better'(LBT) for surface roughness and kerf. The equation for normalization for Higher the better is

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

And for Lower the better is

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

Where y_i (k) is the i^{th} normalized response value, x_i (k) is observed value for the i^{th} run of the k^{th} response.

- Grey relational coefficient(GRC) is calculated by,

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta_i \Delta_{\max}}{\Delta_i(k) + \zeta_i \Delta_{\max}}$$

Where Δ_{min} and Δ_{max} are the global minimum and maximum values of normalized values respectively of the k^{th} response. ξ_i is the distinguished factor whose values lies between 0 and 1 ehose purpose is to expand or compress the range of grey relational coefficient. Here it is taken as 0.5.

- Grey relational grade (GRG) evaluates the performance of the multi response and it is the weighted summation of all the grey relational coefficients. The expression for calculating GRG is

$$\gamma = \frac{1}{n} \sum_{i=1}^{n} \zeta_i(k)$$

Where ξ_i(k)is Grey relation coefficient, ϒ is the grey relation grade. The optimized values are tabulated in Table 3.

ANOVA is carried out to study the influence of each process parameter on performance measures. It is carried out in

Table 5
Analysis of Variance for Surface Roughness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Water Pressure	2	0.028888	61.00%	0.028888	0.014444	*
Traverse Rate	2	0.006356	13.42%	0.006356	0.003178	*
Abrasive mass Flow Rate	2	0.005243	11.07%	0.005243	0.002621	*
Error	0	*	*	*	*	
Total	8	0.047355	100.00%			

Table 6
Analysis of Variance for Kerf

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Water Pressure	2	0.015532	59.89%	0.015532	0.007766	*
Traverse Rate	2	0.000153	0.59%	0.000153	0.000076	*
Abrasive Mass Flow Rate	2	0.005675	21.88%	0.005675	0.002837	*
Error	0	*	*	*	*	
Total	8	0.025936	100.00%			

MINITAB 18 and tabulated below in Table 4, Table 5 and Table 6.

4. Conclusion

The level with highest grey relational grade is the optimum level. Therefore from the Table 3, level 3 is the optimum level. Optimum values of the process parameters are found to be water pressure = 280 MPa, traverse rate = 1000mm/min, abrasive mass flow rate = 0.350 gm/min. By finding ANOVA individual influence of process parameters are found. Water pressure and abrasive mass flow rate has a strong influence on MRR and kerf. Water pressure and traverse rate have strong influence on surface roughness. Water Pressure is the most influencing parameter amongst all the considered process parameters.

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