Study on Effect of Abrasive Water Jet Machining Process Parameter on Taper Angle during Machining of Epoxy Resin Glass Fibre

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Abstract. Abrasive Water Jet Machining (AWJM) is one of the most advanced machining processes, which has the ability to machine various materials. In this paper, experiment was performed on cutting of epoxy fibre glass by AWJM. Epoxy fibre glass is a composite which consists of fibre glass cloth and epoxy resin as binder, achieved under specific heat and pressure. There are various process parameters such as water pressure, standoff distance, abrasive flow rate, traverse rate, abrasive etc. The water pressure and standoff distance was varied while performing the experiment and rest all parameters were kept constant. From this experiment taper angle was measured and it was observed that taper angle increases as the standoff distance increases, this is because the shape of the jet diverges with larger standoff distance. Minimum taper angle was observed as 0.34° at 32 ksi pressure, having 2 mm standoff distance. It was also observed that width of cut has significant effect on taper angle. From further calculations, the deviation of the cut slot for top width was observed as +1% to 5% and for bottom width it was -1% to 2%.

1. Introduction

Abrasive Water Jet Machining (AWJM) is the most advanced and extensively used machining processes. AWJM is convenient in carrying operations on various materials like glass, composites, metals, etc. Momer and Kovacevic [1] has explained various principles on abrasive water jet machining wherein due to plastic deformation, gradual wear and fracture mechanism by high velocity abrasive water jet the material removal takes place in AWJM. When the operation takes place there are no effects of thermal distortion, high machine versatility, high flexibility and also there is absence of heat which makes it cold machining process and thus due to this there is no any damage to the material, which makes it more advantageous than the other machining process used for cutting, drilling etc. [2].

Composites have become one of the most widely used materials due to their high mechanical strength, stiffness and low density, etc. due to their combined material characteristics. Operations carried out by AWJM on composites have various advantages such as any complex shapes can be manufactured with precision, also good surface finish of the composite material is achieved. Fibre reinforced material is widely used and it needs accurate cutting of processes with efficiency. It cannot
be achieved using non-conventional cutting processes like drilling, electric discharge machining, ultrasonic machining, etc. But among all of these non-conventional techniques AWJM is most feasible method for cutting fibre reinforced materials [3].

Various parameters are associated with AWJM such as water pressure, abrasive flow rate, traverse speed, standoff distance, etc. which affects the surface quality of the machined material. The purpose of this paper is to study cutting of epoxy fibre glass by AWJM by varying process parameters.

2. Experimental Work
2.1 Materials and Methods
In this study, the material used is hybrid composite, manufactured commercial epoxy fibre glass sheet with dimension 550 mm × 200 mm × 5 mm. Density is 1.9 g/cm to 2 g/cm approximately. Glass content is 65 to 70 % and epoxy resin content 30 to 35 % by mass approximately. Properties of the material is taken as follows

Table 1. Properties of epoxy fibre glass

| Sr. No. | Properties                      | Specification |
|---------|---------------------------------|---------------|
|         |                                 | Lengthwise    | Crosswise    |
| 1       | Flexural Strength at 20°C       | 450 N/sq.mm   | 350 N/sq.mm  |
| 2       | Impact Strength at 20°C         | 300 N/sq.mm   | 190 N/sq.mm  |
| 3       | Tensile Strength                | 450 N/sq.mm   | 400 N/sq.mm  |
| 4       | Modulus of elasticity at 20°C   | 25 kN/sq.mm   | 20 kN/sq.mm  |
| 5       | Compressive strength at 20°C    | 390 N/sq.mm   | 500 sq.mm    |

2.2 Equipment
The experiment was conducted on MAXIEM® 1530 Jet Machining® equipped with CNC, gravity feed type abrasive hopper and work piece table dimensions as 3708 mm × 1727mm. The process parameters associated with the machine were as follows

Table 2. Machining Parameters

| Sr. No. | Parameters      | Specification |
|---------|-----------------|---------------|
| 1       | Water Pressure  | 20-43 ksi     |
| 2       | Diameter of orifice | 0.4064 mm     |
| 3       | Diameter of nozzle | 1.0668 mm     |
| 4       | Flow rate of abrasive | 315 g/min     |
| 5       | Abrasive size   | 85 mesh       |
| 6       | Traverse rate   | 50-200 mm/min |
| 7       | Abrasive index  | 0.85          |
| 8       | Stand-off distance | 1-5 mm        |
| 9       | Abrasive diameter | 0.025 mm      |
| 10      | Velocity of jet | 150-300 s     |
2.3 Experimental Design

In this study, through cut square slots of 15 × 15 mm were made on the epoxy fibre glass using AWJM. This operation was carried for 30 numbers of slots on the work piece. The abrasive used to cut the slot was garnet. To conduct the experiment, parameters of machine were considered as control variables as mentioned in Table 2. Wherein pressure was varied from 30 ksi to 40 ksi by varying the standoff distance at an interval of one i.e. from 1 mm to 5 mm for each hole and rest all parameters were kept constant.

After machining, width of cut at top and width of cut at bottom of each slot was measured using digital vernier caliper. This data was used to calculate the taper angle in both the widths i.e. at top and bottom width of the slot. The taper angle formula is as follows [10]

\[
\text{Taper angle (θ)} = \tan^{-1} \left( \frac{W_t - W_b}{2 \times t} \right) \text{ degree}
\]

Where
- \( W_t \) – top width in mm,
- \( W_b \) – bottom width in mm,
- \( t \) – thickness in mm.
3. Results and discussions

3.1 Effect of abrasive particles on width of cut

Table 3. Details of experiment

| Sr No. | Pressure (ksi) | Standoff Distance (mm) | Top Width | Bottom Width | Deviation of top width (%) | Deviation of bottom width (%) | Taper Angle (θ) |
|--------|----------------|------------------------|-----------|--------------|---------------------------|-------------------------------|-----------------|
| 1      | 1.00           | 15.20                  | 14.88     | 1.33         | -0.80                     | 1.83                          |                 |
| 2      | 2.00           | 15.42                  | 14.94     | 2.80         | -0.40                     | 2.74                          |                 |
| 3      | 3.00           | 15.30                  | 14.78     | 2.00         | -1.47                     | 2.97                          |                 |
| 4      | 4.02           | 15.36                  | 14.80     | 2.40         | -1.33                     | 3.20                          |                 |
| 5      | 5.08           | 15.40                  | 14.80     | 2.67         | -1.33                     | 3.40                          |                 |
| 6      | 1.00           | 15.40                  | 15.01     | 2.67         | 0.07                      | 2.23                          |                 |
| 7      | 2.02           | 15.38                  | 15.32     | 2.53         | 2.13                      | 0.34                          |                 |
| 8      | 3.00           | 15.30                  | 15.00     | 2.00         | 0.00                      | 1.71                          |                 |
| 9      | 4.00           | 15.42                  | 15.00     | 2.80         | 0.00                      | 2.40                          |                 |
| 10     | 5.05           | 15.60                  | 15.00     | 4.00         | 0.00                      | 3.43                          |                 |
| 11     | 1.02           | 15.30                  | 15.10     | 2.00         | 0.67                      | 1.14                          |                 |
| 12     | 2.03           | 15.34                  | 15.00     | 2.27         | 0.00                      | 1.94                          |                 |
| 13     | 3.00           | 15.18                  | 14.82     | 1.20         | -1.20                     | 2.06                          |                 |
| 14     | 4.06           | 15.34                  | 14.82     | 2.27         | -1.20                     | 2.97                          |                 |
| 15     | 5.05           | 15.38                  | 14.84     | 2.53         | -1.07                     | 3.09                          |                 |
| 16     | 1.02           | 15.40                  | 15.00     | 2.67         | 0.00                      | 2.29                          |                 |
| 17     | 1.52           | 15.40                  | 14.92     | 2.67         | -0.53                     | 2.74                          |                 |
| 18     | 3.05           | 15.38                  | 14.88     | 2.53         | -0.80                     | 2.86                          |                 |
| 19     | 4.06           | 15.44                  | 14.84     | 2.93         | -1.07                     | 3.43                          |                 |
| 20     | 5.08           | 15.42                  | 14.80     | 2.80         | -1.33                     | 3.54                          |                 |
| 21     | 1.02           | 15.30                  | 14.92     | 2.00         | -0.53                     | 2.17                          |                 |
| 22     | 2.03           | 15.38                  | 14.92     | 2.53         | -0.53                     | 2.74                          |                 |
| 23     | 3.05           | 15.42                  | 14.92     | 2.80         | -0.53                     | 2.86                          |                 |
| 24     | 4.06           | 15.52                  | 14.98     | 3.47         | -0.13                     | 3.09                          |                 |
| 25     | 5.08           | 15.74                  | 15.00     | 4.93         | 0.00                      | 4.23                          |                 |
| 26     | 1.02           | 15.34                  | 15.00     | 2.27         | 0.00                      | 1.94                          |                 |
| 27     | 2.03           | 15.42                  | 15.00     | 2.80         | 0.00                      | 2.40                          |                 |
| 28     | 3.05           | 15.30                  | 15.08     | 2.00         | 0.53                      | 1.26                          |                 |
| 29     | 4.06           | 15.70                  | 15.10     | 4.67         | 0.67                      | 3.43                          |                 |
| 30     | 5.08           | 15.64                  | 15.10     | 4.27         | 0.67                      | 3.09                          |                 |

From the above calculations it was noted that the top width is larger than the bottom width of each slot. The deviation of the cut slot for top width was observed as +1% to 5% and for bottom width it was -1% to 2%. Wang and Wong [4] has explained that initially at the time of cut the kinetic energy of the abrasive particles is very high but as it moves downwards the abrasive particles loose K.E. and relative strength of the jet i.e. it gets narrower as it moves downwards, thus the bottom width is smaller than the top width. We notice that the taper of cut is varying from 0.2° to 4.5°, Khan [5] has explained that when garnet is used as abrasive the taper of cut is comparatively higher. Because the sharpness of the garnet abrasive is reduced and hence the bottom width is also smaller than the top width.
3.2 Effect of standoff distance on taper angle at different pressures

Figure 3(a) and 3(b) shows the effect of standoff distance on angle of taper with varying pressures. From below graphs, it is observed that as the standoff distance increases the angle of taper also increases. Khan [5] explained that the nature of jet is dependent on the standoff distance applied. The increase in the taper of angle is due to the reason that as standoff distances increases the jet focus area diverges and thus there is increase in the width of cut.

![Figure 3(a)](image1)

*Figure 3(a). Effect of standoff distance on taper angle at 30 ksi, 32 ksi and 34ksi.*

![Figure 3(b)](image2)

*Figure 3(b). Effect of standoff distance on taper angle at 36 ksi, 38 ksi and 40ksi.*
4. Conclusion
From the above observations, it can be concluded, as the standoff distance increases then the angle of taper also increases, this happens because as the standoff distance increases, the jet focus area diverges. Minimum taper angle was observed as 0.34° at 32 ksi pressure, having 2 mm standoff distance. It was also observed that the bottom width of cut is smaller than width of cut at top, which is because at impingement of the jet, the kinetic energy is higher and when the jet moves downwards, the abrasive particles loses their kinetic energy. Hence there is deviation in the width of cut. The deviation of the cut slot for top width was observed as +1% to 5% and for bottom width it was -1% to 2%.

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