INFLUENCE OF AWJM PARAMETERS ON GLASS/EPOXY THIN LAMINATE USING TAGUCHI ANALYSIS

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ABSTRACT

Experimental investigations were conducted to assess the influence of abrasive water jet machining (AWJM) parameters on the machining performance criteria namely surface roughness and kerf taper ratio. The approach was based on Taguchi's Method and Analysis of Variance (ANOVA) to optimize the AWJM parameters for effective machining of woven glass fibre reinforced epoxy composite. It was found that hydraulic pressure, standoff distance, abrasive mass flow rate and cutting orientation were the significant control factors; the cutting orientation was the insignificant control factor in controlling the machining performance criteria. Mathematical models were established using linear regression analysis to predict the surface roughness and kerf taper ratio in terms of the cutting parameters of AWJM. For effective machining of glass fibre reinforced epoxy composites, verification of the improvement in the quality characteristics has been made through confirmation tests with respect to the chosen reference parameter setting. It was confirmed that determined optimal combination of AWJM parameters satisfy the real need for machining of glass fibre reinforced epoxy composites in practice.

INTRODUCTION

Abrasive water jet machining (AWJM) process is one of the non-traditional machining processes that has been used extensively in various industry-related applications. The basic principles of abrasive water jet machining (AWJM) were reviewed in detail by Momber and Kovacevic (1998). This technology is less sensitive to material properties because it does not cause chatter, has no thermal effects, imposes minimal stresses on the workpiece, has high machining versatility and high flexibility. However, the AWJM process has some drawbacks; for instance, it may generate loud noise and a messy working environment (Choi and Choi, 1997; Wang and Wong, 1999).

The use of composite materials has gained increasing acceptance in our modern technology applications. Generally, composite materials have better mechanical properties such as low densities, high strength, stiffness and abrasion and impact and corrosion resistances. This can be done by combining two or more different materials which can produce a better combination of properties from both constituent phases (Callister, 2003; Komanduri *et al.*, 1991). Fibreglass is widely used as a reinforcement for composite material due to its unique characteristics which include high weight to strength ratio, is easily available and fabricated, has excellent corrosive resistant and design flexibility, is a good electrical insulator, has a high fatigue endurance limit, and is extremely cost-effective in certain manufacturing methods (Strong, 1989; Callister, 2003).

There are numerous related parameters and factors of the AWJM process that can influence the surface quality of the AWJ machined surfaces. However, in the present study only six factors are considered for analysis; 1 two-level factor and 5 three-level factors. By using conventional experimental methodology or a full factorial experiment, 486 distinct test conditions are needed to study all of the factors and their levels. Hence, it is neither economical nor practical to conduct a full-factorial experiment. It is therefore suggested to apply Design of Experiment (DOE) using Taguchi's orthogonal array to reduce the number of experiments to a more practical and affordable size.

MATERIALS AND METHOD

Materials

In these experiments, E-glass fibre of woven (plain weave) TGF-800 was used as reinforcement materials. The glass filament had a diameter of 10 μm. The width of the woven glass fibre strand was 4 mm and the thickness was 0.3 mm from direct roving. The matrix resin used was thermosetting epoxy resin (WM-215 TA) which was mixed with hardener WM-215 TB at a ratio of 4:1 (as recommended by manufacturer). The properties for both fibre glass and epoxy are shown in Table 1 (Ahmed Nazrin, 2005).

Sample Fabrication

Fibreglass/Epoxy laminates were prepared using the hand lay-up process. The woven fibre fabrics were cut into squares of 150 mm x 150 mm. The orientation of fibre (i.e. the length, the width, and the face) within the fabric was kept constant all the time during the lay-up process and they were considered as bidirectional laminates [0°/90°]. The layers were properly stacked into 9 plies so as to achieve approximately 5 mm thickness upon curing. The volume fraction of the laminate was around 0.50.

Equipment

The equipment used for machining the samples was Excel-CNC abrasive waterjet cutting machine equipped with an Ingersold Rand model of water jet pump with the designed pressure of 50,000 psi.

Experimental Design

The 6 machining parameters selected for the experimental design were abrasive types, hydraulic pressure, standoff distance, abrasive mass flow rate, traverse rate and cutting orientation (Table 2). The parameters and levels were selected primarily based on the literature review of some studies that had been documented on AWJ machining on graphite/epoxy laminates (Arola and Ramulu, 1993), Kevlar composite (Rahmah *et al.*, 2003), ceramic materials (Chen *et al.*, 1995), and structural metal alloys (Conner *et al.*, 2003). Based on Taguchi's Method DOE with 6 factors (5 three-level and 1 two-level factor), L_{18} ($2^1 \times 3^7$) orthogonal array was selected for these experiments. L_{18} orthogonal array required 18 numbers of experiments to be conducted.

For each experimental run, the machining parameters were set to the pre-defined levels according to the orthogonal array (Table 3). The test specimen was machined according to a CNC programme in which a slot was machined 10 mm in length with full penetration as shown in Figure 1. Then it was machined 20 mm x 20 mm to detach the test specimen, thus, enabling the measurement of surface quality at the kerf face. All machining procedures were done using a single-pass cutting. All machined surfaces with respect to the weft direction as well as with respect to the warp direction are considered to be in the fibre orientation of [0°/90°], whereas, the +45° and -45° are those directions at positive angles of 45° and 315° respectively with respect to the traverse axis. Meanwhile, the +22.5° and -22.5° settings are those directions at positive angles of 22.5° and 337.5° respectively with respect to the traverse axis (Figure 1).

A surface roughness measuring device, SURFPAK SV-514, which has a cone-shaped diamond stylus with a diameter of 10 μm and 90° tip angle was used in this experiment. The measurement of surface roughness was obtained across the thickness of the test sample surface. Surface roughness profiles were taken from 0.5 mm above the bottom surface to 0.5 mm below the top surface to avoid the effects of jet exit and entrance respectively.

All measurements were acquired using 0.8 mm cutoff length. The values of surface roughness (R_a) were taken three times for each sample, so that their averages could be calculated in order to minimize the variability. The kerf taper ratio (T_R) was calculated by finding the ratio of top kerf