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Cutting Characteristics of Carbon Fiber

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Abstract—**CFRP (carbon fiber reinforced plastic), which is composed of carbon fibers in a resin matrix, is an extremely strong and light composite material that has found use in the aerospace and automotive industries. CFRP boards are very difficult to machine using common machining processes. Various machining artifacts, such as burrs and delamination, occur frequently when machining CFRP. Adequate techniques for machining CFRP have not yet been established. Recently, electroplated diamond wire machining technology has found use in cutting hard, brittle materials such as silicon and sapphire. In this study, we used an electroplated diamond wire saw to cut a CFRP work piece. We quantified the cutting forces imposed on the work piece and observed the surface state of the work piece after cutting. We demonstrated that an electroplated diamond wire tool is suitable for the high-quality machining of CFRP boards.**

***Index Terms*—carbon fiber**

I. Introduction

The use of composite materials based on carbon fiber reinforced plastics (CFRP) has grown considerably in last two decades, widely in the aeronautic, aerospace, sporting, military vehicle parts and automotive industries. They are well suited for design applications in which the use of their high stiffness and strength, low weight, and good corrosive properties is needed [1].

CFRP pultruded plates offer several advantages over steel including resistance to corrosion, low weight, and excellent mechanical strength. The specific properties of carbon fibers are high tensile strength in fiber direction and low density, are only then successfully applied in high performance composite materials. In certain applications, some other fibers such as glass fibers, Kevlar and aluminum may also be used along with carbon fibers. Although CFRPs are usually fabricated to near net shapes by autoclave moulding, compression moulding or filament winding [6], a post machining operation, such as tuming, milling or drilling is often necessary and must be performed to assure that the composite parts meet dimensional tolerance, surface quality and other functional requirements [2].

II. Performance Test of Fiber Composites

Fatigue Fig. 1 (Curtis 1989) shows typical S-N curves for three unidirectional composites (CFRP, glass fiber reinforced polymers, and Kevlar fiber reinforced polymers). With CFRP it has been demonstrated (Curtis 1989) that the matrix composition has a greater effect on the fatigue performance than the type of fiber [4]. There was no significant difference in the fatigue performance of four different CFRP composites when four different carbon types were placed in the same matrix. However, using the same fiber in different epoxy resin matrices did influence the slope of the fatigue S-N curve [3], [4].

When compared with other engineering materials, composites exhibit superior fatigue performance. For tendons in the North Sea oil industry, researchers (Walton and Yeung 1987) have found that composite tendon members can easily surpass the performance available from steel [3-4].

In materials with a crystalline structure, fatigue initiates at a defect and propagates, forming a crack that grows with increasing load cycles until failure.

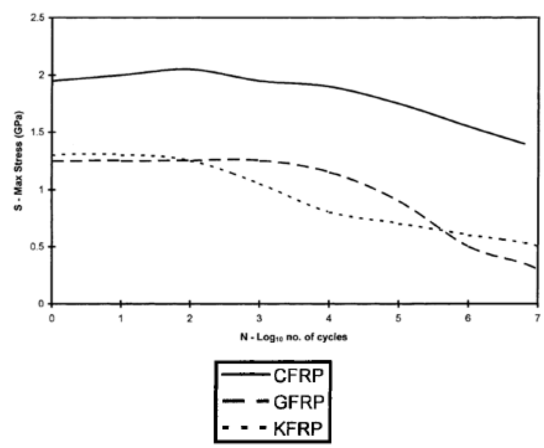

Fig. 1. Typical S-N Curve for Unidirectional Composites

The individual fibers within unidirectional composites have relatively few defects, and any crack that forms does not travel across the matrix. It is these properties that contribute to the good fatigue performance of unidirectional composites [4], [5].

III. Advantages of CFRP

A unique and distinct appearance that's nearly impossible to replicate. Excellent strength to weight ratio, compared to other materials. Works well with other materials (fiber, plastics, wood, concrete and metals). Suitable for complex contours and designs. Superior fatigue properties. High Stiffness [6]. High heat tolerances and resistance. Flexible thermal and electrical properties. Corrosion resistance (with proper resins). Varying classifications (tensile modulus) of strength. The strongest carbon fiber is 10x stronger and 5x lighter than steel. The strongest carbon fiber is 8x stronger and 1.5x lighter than aluminum [7].

IV. Disadvantages of CFRP

Manufacturing of CFRP is a complicated process that requires advanced technical equipment. Cost also depends on the number of factors that include market conditions, fiber tow size and type of carbon fiber. Even though the rate is high CFRP possesses unique properties and is highly demanded in many technical spheres. CFRP is relatively brittle [7].

V. Machinability of CFRP

There are several mechanical processes exploited and studied in the CFRP machining area, including conventional processes like turning, milling, drilling, etc., unconventional processes like laser ablation, water-jet cutting, etc., and some other hybrid processes like laser-assisted cutting, vibration-assisted cutting, minimum quantity lubricant assisted machining, etc. [8].

Turning, one of the most widely used processes in CFRP machining, is predominantly used to achieve the desired dimensional tolerances on cylindrical surfaces. Among the possible tool materials used in CFRP turning are ceramics, cemented carbides, cubic boron nitride (CBN), and polycrystalline diamond (PCD) [8].

Milling is used to machine accurate dimensions and complex shapes on CFRP components. It is considered as a corrective operation to produce well defined and high-quality surfaces [10].

Drilling is the principal operation for making bolted or riveted assemblies in CFRP components or structures used in industry. For example, more than 100,000 holes are made for fasteners such as rivets, bolts, and nuts in a small single-engine aircraft, while millions of holes are made in a large transport aircraft. Delamination is a mode of failure for composite materials and steel. Delamination and surface quality were experimentally found to be influenced by the cutting parameters, drill bit geometry, and cutting force. For the same drill material, cutting speed was found to have an insignificant influence on the cutting force while it was suggested that the decrease in the feed rate at exit can reduce the delamination factor [9].

Shaping and edge trimming of CFRPs is commonly exploited to simulate orthogonal cutting conditions. The first experimental investigation in CFRP machining was performed on an instrumented shaping machine by Koplev [8], aiming to carry out a simplified orthogonal process characterized by a well-defined geometry. Roughness of CFRP laminates was found to be sensitive to fiber orientation along the cutting direction rather than directions perpendicular to the cutting direction. No intrinsic reason for the variation of roughness sensitivity was given in their work [9].

VI. Wire Cut EDM

Wire electrical discharge machining (WEDM) is among the more widely known and applied nontraditional machining processes in industry today. In this procedure, improvements to the process mechanism and control have rapidly been taking place. WEDM can machine harder, they are higher strength, corrosive and wear-resistant, and difficult to machine materials. With WEDM, it is also possible to machine complicated shapes that cannot otherwise be achieved using traditional machining processes, such as turning, milling, and grinding. Applications of WEDM include extrusion dies, fuel injector nozzles, aircraft engine turbine blades, and machining of difficult-to-machine materials like tool steel, titanium, and metal matrix composites (MMCs), and cemented carbides. Besides machining electrically conductive work pieces, some WEDM work has also been reported on insulating ceramics and non-conductive materials [10-11].

As for WEDM, demand is on the rise for high-speed cutting and high-precision machining for improving the productivity of molds as well as for achieving high-quality machined work pieces. Wires used in WEDM are the core of the system. Brass wire electrodes are extensively used as WEDM tools. However, along with recent variations in manufacturing field applications, there is an expanding demand for wire electrodes with superior performance to the conventional brass wire electrodes [10].

High-performance wires, including coated, composite, and diffusion-annealed wires are characterized by high conductivity and good sparking ability. These electrodes are generally zinc-coated wires with a copper-brass alloy or steel core, the brass containing either a small amount of chromium or high concentration of zinc. At present, WEDM users are interested in shortening the machining time of products. A new, high-performance EDM wire would be expected to provide both high cutting speed and improved accuracy [10], [11].

VII. Wire EDM Process

In WEDM, material removal is based upon the electro discharge erosion effect of electric sparks occurring between the wire electrode and work piece. The two are separated by a dielectric fluid, as shown in Fig. 2. A pulse voltage is applied between the wire electrode and work piece in the processing fluid to melt the work piece surface with the thermal energy of a spark discharge, while simultaneously removing machining dust through a vaporizing explosion and recirculation of the processing fluid. Continuous machining thus becomes possible while running the wire electrode. The residue ensuing from the melting and vaporization of a small volume of the surfaces of both work piece and EDM wire electrode is contained in a gaseous envelope (plasma) [12].

The plasma eventually collapses during off-time. The liquid and vapor phases created by the melting and vaporization of the material are quenched by the dielectric fluid to form solid debris. This process is repeated at nanosecond intervals (depending on the cycle time) along the length of the wire in the cutting zone [12].

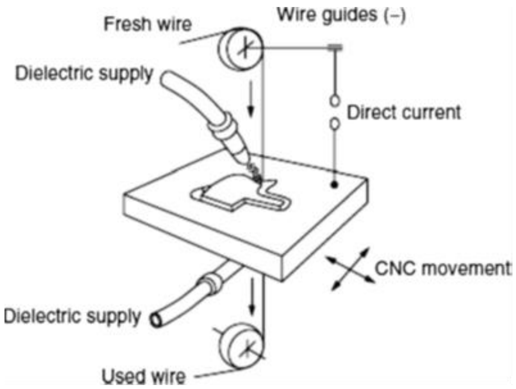

Fig. 2. Wire electric discharge machining (WEDM) schematic diagram

To achieve a successful operation, selecting the correct wire electrode for WEDM is a very challenging task. As a result, experimentation with different wire electrodes is essential if optimum results are to be achieved. The wire electrodes used in WEDM must have two important characteristics: high electrical conductivity and sufficient mechanical strength [13].

VIII. Influence of WEDM in CFRP

In this work, various EDM cutting conditions such as pulse-on time, pulse-off time, peak current, open circuit voltage and speed of electrode rotation were selected for this work for obtaining optimum EDM cutting conditions for CFRP material. The electrical discharge machining conditions selected for the work [13]-[15].

EDM cutting parameters such as material removal rate, electrode wear rate, gap size and surface roughness were evaluated when cylindrical cavity of 1.0 mm in depth was machined as shown in Fig. 3. [16].

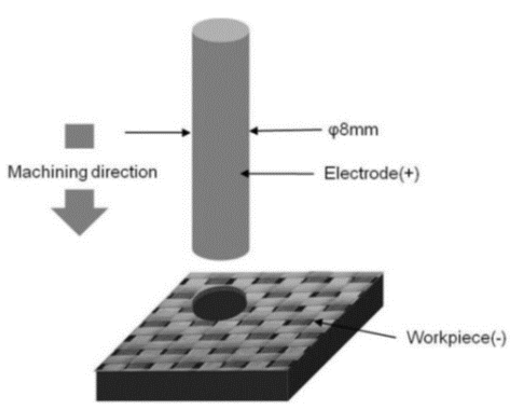

Fig. 3. EDM experiment

Material removal rate was calculated as the weight difference after machining from it before machining of work piece per required cutting time. Changes in the tool weight, material weight, and elapsed time were recorded after each machining. The work piece weight was measured by using an electronic balance of sensitivity 0.1 mg. Electrode wear rate was calculated as the percentage of electrode wear length to the depth of the machined work piece cavity. For obtaining the experimental data, electrical discharge machining was performed on the top plane of the laminates [18]-[20].

The surface roughness of the CFRP machined area was measured with the help of surface texture measuring instrument tracing driver Surfcom (Tokyo Seimitsu). The Ra values are used to quantify the surface roughness. The cutoff length for each Measurement was taken as 0.8 mm. Examining of the machining accuracy and damage of the as-machined surface can be done using both a Keyence VH-7000 (USA) optical digital high definition microscope with different magnifications and Keyence VE-8800 (USA) scanning electron microscope (SEM) at a beam voltage of 20kV [20]-[23].

IX. Conclusion

The tool wear has a strong influence on feed force and surface roughness. For finishing operations, only diamond tools can ensure a surface roughness of about 2.5-micron mm Ra. There is a strong influence of the matrix content, fiber orientation and fiber type on the machinability of CFRP composite. CFRP composites had an inherently lower damping ratio than the neat epoxy, the former composites showed a higher rate of increase in damping ratio than the epoxy Nano composites. Micro-sized through holes in CFRPs is an essential design requirement for proposing their applications in miniaturized products such as micro-robotics and fiber optics applications.

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